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PHOTOCELL THEORY AND PRACTICE.*

BY

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I. HISTORY OF PHOTO-ELECTRIC EFFECT.

The discovery of photo-electric effect and subsequent development of photo-electric cells presents a remarkable chapter in scientific research.

The initial discovery was made by Herz [1] in 1887, during his experiments with the oscillating spark discharges, the work which was the foundation for our wireless. He noticed that a spark gap illuminated by another spark discharges more readily than one which was screened in a dark box. The effect attracted his attention, and by a series of ingenious deductions and confirming experiments, he finally traced this phenomena to an effect of ultra-violet light upon the spark discharge.

Herz published his observation without attempting to advance a theory as to how such observed phenomena could occur.

Wiedemann and Ebert [2] jointly confirmed Herz's results, and in addition, demonstrated that the phenomenon was confined altogether at the negative terminal of the spark gap.

* Presented at a meeting held Thursday, February 26, 1931.

[1] Herz, *Ann. d. Phys.*, 31, 421, 1887.

[2] Wiedemann and Ebert, *Ann. d. Phys.*, 33, 421, 1888.

(Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

Hallwachs [3] in the following year, by modifying the experiments, demonstrated that a negatively charged body loses its charge under the influence of ultra-violet light. An insulated system acquires a positive charge under the same conditions. He formulated this in a postulate now bearing his name: "Negative electricity leaves a body under the influence of ultra-violet light and follows electro-static lines of force"

Stoletow,[4] in 1890, by illuminating a polished metallic surface connected to a galvanometer in series with a voltaic pile, succeeded in producing a continuous current in the circuit, thus approaching the recent methods for measuring photo-electric effect.

The next great advancement in the art of photo-electricity was made by two famous co-workers, Elster and Geitel.[5] It had been observed by them that metals such as aluminum, magnesium and zinc are more sensitive than others to photo-electric effect. Since all these metals were electro-positive, chemically speaking, they concluded that it would be reasonable to expect still better results from more electro-positive metals, and proceeded to investigate the photo-electric effect on the alkali metals. These metals are in the first group of Mendelejeff's Chart of Elements, and are: Lithium, Sodium, Potassium, Rubidium and Cesium. Since these metals are highly active, and almost instantly react with air and water vapor, the experiments were confined at first to the amalgams of the alkali metals, which proved to be many times more sensitive than anything tried before. But what was the most remarkable, these alkali amalgams produced a strong photo-electric effect while illuminated through a screen of the ordinary glass, which was known to absorb all the ultra-violet radiation. Therefore, the photo-electric action was due to the visible light, while all the previous investigations yielded the results only under ultra-violet. This meant that alkali metals were photo-electrically active to ordinary visible radiation. Here for the first time, we came in contact with the photo-electric effect, as we understand it in most of our practical applications.

[3] Hallwachs, *Ann. d. Phys.*, 33, 301, 1888.
[4] Stoletow, *Journ. de Physique*, 9, 486, 1890.
[5] Elster and Geitel, *Ann. d. Phys.*, 41, 161, 1890.

In the next year, Elster and Geitel described in detail the manufacture of sodium amalgam photo-electric cell, entirely enclosed in glass and well evacuated; this cell thus being the first photo-electric cell that strongly resembled our modern cells.

We should mention, however, that the development of the practical photo-electric cell was not the ultimate goal of all these early investigations. It was rather quite an insignificant side line. The phenomenon itself, interested the scientists immensely, because of the impossibility of its explanation by classical physics. We should remember that the epoch around 1890 was the beginning of the disproving of the old classical theory of the continuous flow of electricity and the building up of the quantum theory. It was at that time that J. J. Thompson [6] isolated and measured the carrier of electricity in the Geissler gas discharge tube. From the results of his experiments he concluded that the electricity consists of a great number of small particles which are deflected by magnetic field as if they are negatively charged.

The mass of this carrier of electricity was less than 1,000 that of a hydrogen atom, the lightest of all elements. This newly found sub-division of the matter has been subsequently called an electron. Thompson noted that electrons from all sorts of metals were identical in charge and the mass.

Elster and Geitel applied these results to photo-electric emission and found that the magnetic field influences the photo-electric emission in the same way as if it consisted of negative particles, exactly as in the Thompson experiments.

In the same year, Lenard [7] confirmed these results in carefully arranged experiments, and finally proved beyond question that the photo-electric carrier is indeed an electron. The mass and charge of this electron measured by Lenard and other investigators coincide exactly with that of the electrons obtained from other sources.

Out of the experimental work of the early investigators gradually crystallized two fundamental laws of photo-electric action. The first law may be worded:

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[6] Thompson, *Phil. Mag.*, 48, 547, 1899.

[7] Lenard, *Ann. d. Phys.*, 2, 359, 1900.

"The number of electrons released per unit time at a photo-electric surface is directly proportional to the intensity of the incident light."

The second law is one of a more surprising nature:

"The maximum energy of electrons released at a photo-electric surface is independent of the intensity of the incident light, but is directly proportional to the frequency of light."

Considered together, these two fundamental laws give quite a peculiar conception of the action of the light. As far as the photo-electric phenomenon is concerned, one is not to regard a glaring intense beam of light as essentially more violent in its action than a dimly visible beam of the same kind of light, but rather to regard the more intense as simply operating upon a larger number of objects per unit area of illuminated surfaces.

To complete the fundamental idea of the photo-electric phenomena, we should add here that both the number of electrons emitted and their velocity are independent of the temperature, within a wide range.

All these properties of photo-electric emission cannot be satisfactorily explained on the ground of the classical physics. In 1905, Einstein [8] proposed that photo-emissive phenomena could be accounted for by adopting Planck's quantum theory of radiation, and assuming that when a quantum of energy $h\nu$ (h being Planck's constant and ν the frequency of light) reacted with an electron, the latter would acquire the total quantum and be released in possession of an equivalent amount of kinetic energy. Einstein's equation for the photo-electron is:

$$\tfrac{1}{2}mv^2 = h\nu - P,$$

where the first part of the right side of the equation represents the energy of absorbed quantum, and P, the energy lost by the electron in freeing itself from the influence of surrounding atoms while leaving the parent body. This P is called a "work function" of a given surface. We notice at once that if P equals $h\nu$, the velocity of the emission of the electron is zero, and hence, there must be a certain minimum frequency, say ν_0, below which no frequency is able to liberate the electron.

[8] Einstein, *Ann. d. Phys.*, 17, 132, 1905.

$$\tfrac{1}{2}mv^2 = h(\nu - \nu_0).$$

This minimum value is known as the "threshold frequency." Its realty is proved by experiments.

To illustrate Einstein's equation, let us consider metal potassium, frequently used in photo-electric cells. For the normal metal, which has not been sensitized, the "threshold" is close to 7,000 ÄU, corresponding to a characteristic frequency of about 4.3×10^{14} sec.$^{-1}$. Einstein's equation implies that if the light is slightly redder than this, it may fall on potassium for centuries, no matter how strong it may be, without causing the emission of electrons. But, if the light has greater frequency, it will at once bring about the liberation of electrons, and the actual measurement reveals that these electrons are emitted after an exposure of only one ten-millionth of a second.[9]

II. THE METHODS OF PREPARATION OF THE PHOTOCELL.

Photocells which respond to visible radiations all have for their sensitive material one of the alkali metals, lithium, sodium, potassium, rubidium, cesium or one of the alkaline earths, calcium, strontium or barium.

It is convenient to classify cells by the general manner in which the sensitive element is introduced. The methods of deposition generally employed may be grouped under four headings: from solution, by distillation, by electrolysis, or by disintegration.

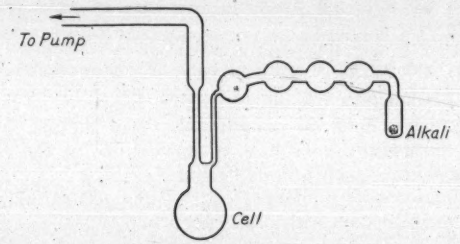
The method of solution is not now in common use. The alkali metal is dissolved in a volatile solvent and the solution is applied to the portion of the bulb to be sensitized. Upon evacuation of the bulb, the solvent evaporates, leaving a rather uniform film of metal on the wall. This was the only method by which Kunz was able to manipulate lithium. As a solvent he used æthylamine.

Distillation of the alkali metals, sodium to cesium, may be carried out either from an external supply through a connecting glass system to the cell, or by a direct evaporation from a pure supply introduced bodily into the cell before evacuation. The alkalies can be distilled from their original

[9] Lawrence and Beams, *Phys. Rev.*, 29, 903, 1927.

shape, as they are purchased on the market. It is a common practice to introduce a piece of metal in a rather remote part of a glass appendage connected through a series of condensing chambers to the cell as shown in Fig. 1. The melting temperature of alkali is very low, being 186° C. for lithium and 26.5° C. for cesium with the other metals in between. The distillation may be effected by the simple expedient of applying a Bunsen flame or by a small electric oven. The alkalies readily melt and begin to distill, becoming purer at each stage until ultimately the vapor is driven into the cell after which the whole appendage with its chambers is sealed off. Within the cell proper, the alkali may be permitted to condense

FIG. 1.



directly upon the glass walls, or else upon a conducting metallic coating, such as silver, previously deposited.

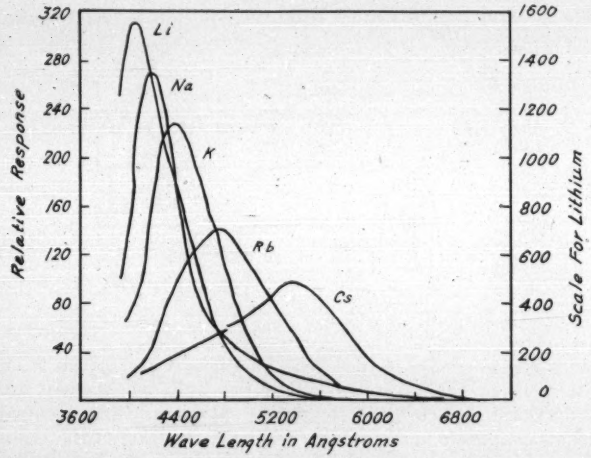
As it was mentioned before, each pure metal has its own work function and its own threshold frequency. Precisely in the same way, each alkali metal responds best to a certain frequency, i.e.: to a particular color. Typical color sensitivity curves for all the alkali metals are shown in Fig. 2 from Li to Cs.[10]

All alkali cells prepared either by the method of solution or of distillation, may be increased in sensitivity by a hydrogen discharge, with the one exception of cesium. For example, potassium may be made a hundred times as sensitive as in its natural state. With a pressure of 2 or 3 mm. of hydrogen, an applied voltage of about 300 volts between anode and

[10] Seiler, *Astrophys. Journ.*, 52, 129, 1920.

alkaline cathode will cause a glow discharge to pass through the gas. The potassium at once becomes brilliantly colored, in its final state becoming a sort of peacock blue. The process requires only a few seconds, but the coloration and the corresponding increased sensitivity will gradually disappear unless an inert gas such as argon or neon is introduced after the excess hydrogen is pumped out. With the inert gas present, the cell may remain sensitive for many months. These kinds

FIG. 2.



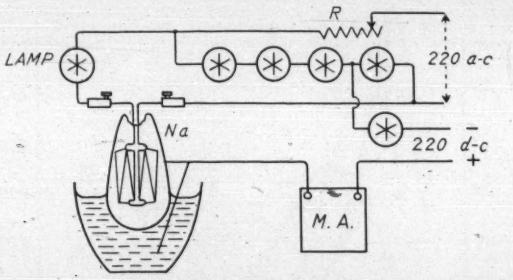
of cells were actually developed by Elster and Geitel, and the method of manufacturing remained for many years without any alteration as it was originally introduced. Perhaps more cells of this type have been made until recently than of any other kind.

At least sodium and potassium may be deposited within a cell by electrolysis through the glass walls themselves. R. C. Burt [11] has developed and described a process by which the

[11] Burt, *J. O. S. A.* and *R. S. I.*, 11, 87, 1925.

purest of sodium can be introduced into an evacuated bulb by this method. Figure 3 shows a diagram of the circuit similar to the one used by Burt in 1925. The bulb into which the sodium is to be introduced must be made of soda glass and can be a regular bulb from a 60 watt lamp. It is placed in a bath of molten sodium nitrate ($NaNO_3$) (melting point 312° C.), which also contains a heavy copper wire as an anode. The part of the current starting from the anode flows first through the molten sodium nitrate, then through the hot glass, which at this temperature is slightly conductive, then through the electronic emission to the incadescent filament. The sodium ions, liberated from the solution by electrolysis,

FIG. 3.



enter the glass and replace the ions which are driven from the glass to the inner surface of the bulb where they are neutralized by electrons from the filament. The neutral atoms evaporate and condense on the cooler part of the bulb. A considerable amount of metallic sodium can be introduced in the evacuated bulb without the slightest damage to the glass of the bulb. The sodium is very pure, but, unfortunately, the sensitivity of such a cell is not high compared with that of more recent cells.

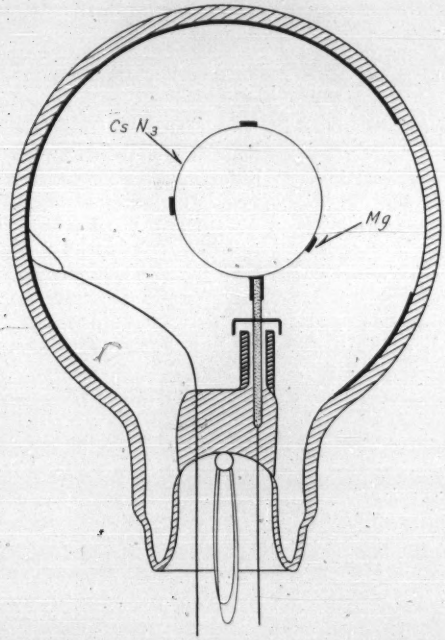
Burt's efforts to send potassium through glass failed because when sodium atoms were displaced by the dissimilar potassium atoms, molecular strains were introduced which resulted in fracture of the bulb. The following year, the writer[12] succeeded in the WEMCO Research Laboratory in

[12] Zworykin, *Phys. Rev.*, **27**, 813 (A), 1926.

accomplishing the desired results by utilizing a pure potash glass containing no soda. With bulbs of this material, and a bath of molten potassium nitrate (KNO_3) photocells with extremely pure potassium were made.

Disintegration of compounds may be very simply accomplished by thermal treatment. This scheme has been successfully employed in cesium-magnesium cells.[13] The mechanical structure can be clearly understood from Fig. 4.

FIG. 4.



The press contains two wires, one of which is sealed to the inner wall of the bulb, the other being centrally located and

[13] Zworykin and Wilson, *J. O. S. A.* and *R. S. I.*, 19, 81, 1929.

provided with a metallic ring. Upon the ring are welded a few bits of magnesium and there is painted a small quantity of an aqueous solution of cesium trinitride (CsN_3). After the cell is exhausted and baked out in the usual manner, it is

FIG. 5.

at once sealed off from the vacuum pump. When the ring is heated by a high frequency field, the magnesium evaporates and condenses on the walls of the bulb, and at the same time the trinitride is thermally decomposed. The free nitrogen

is chemically bound by the active magnesium during its flight through space, and ultimately the hot cesium vapor condenses in an invisibly thin film upon the silvery magnesium coating. A window is made in an appropriate position by applying a Bunsen flame externally, and the cell is done. The sensitivity of the cesium-magnesium cell is of the order of 2 microamperes per lumen, roughly ten times that of the hydrogenated potassium cell. Figure 5 shows the appearance of such a cell and Fig. 6 the color sensitivity curve.

Case [14] also makes use of thermal decomposition in his barium cell. A barium compound is applied to a ring-shaped filament which is later heated by current until barium and probably barium suboxide are released and evaporated over onto a silver coating which has been previously deposited. The surface is further sensitized by ionic bombardment. Figure 7 shows the color sensitivity of this cell.

The most sensitive cell so far ever produced, as revealed in the literature, is the cesium-oxide-silver cell originally developed by Koller [15] and Thompson of the General Electric Company, and later improved in conjunction with the Research Laboratories of the WEMCO. In one form of this cell, cesium released by thermal decomposition of a pellet consisting of cesium dichromate and silicon condenses on the silver cathode plate which has been oxidized by the electric discharge in pure oxygen. Baking in a furnace causes a reaction between the alkali and the silver oxide which ultimately results in the formation of oxides of cesium with doubtless a monatomic layer of cesium overall. Figure 8 shows the appearance of a cell of this type. In a class by itself is the cell developed in the Bell Telephone Laboratories by M. E. Ives and O. R. Olpin.[16] This cell, intermediate in sensitivity between the cesium-magnesium and the cesium-oxide-silver types, has as the alkali either sodium or potassium. Greater sensitivity is attained by the introduction of slight traces of sulphur and oxygen. Also, organic dyes like "alizamine blue" are employed for staining the surface in

[14] Case, *Trans. Amer. Electrochem. Soc.*, 39, 423, 1921.
[15] Koller, *J. O. S. A.* and *R. S. I.*, 19, 135, 1929.
[16] Olpin, *Phys. Rev.*, 33, 1081 (A), 1929.

FIG. 6.

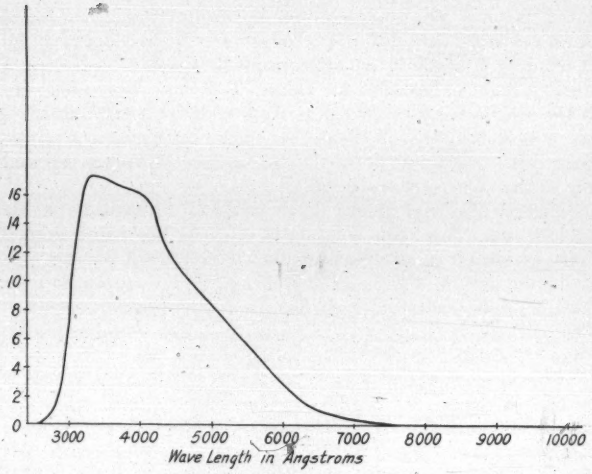
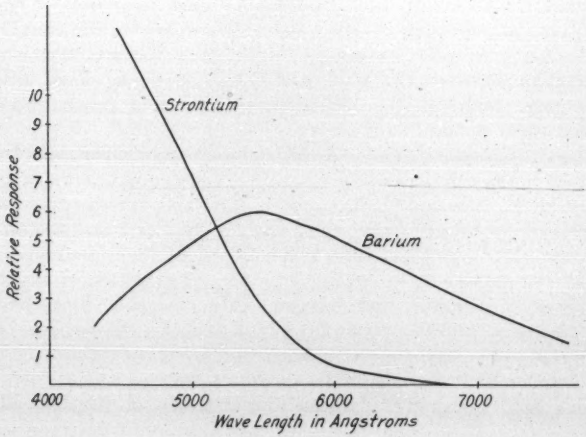
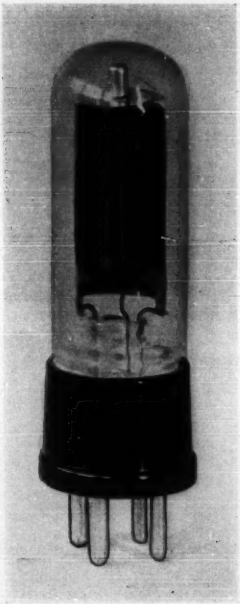

16
14
12
10
8
6
4
2
0
3000
4000
5000
6000
7000
8000
9000
10000
Wave Length in Angstroms

FIG. 7.


Strontium
Barium
Relative Response
10
9
8
7
6
5
4
3
2
1
4000
5000
6000
7000
Wave Length in Angstroms

analogy with the sensitization of photographic emulsion to longer wave-lengths. The composite treatment has the effect of creating a red sensitivity, more noticeable with sodium than with potassium.

FIG. 8.



The sensitivity of this cell without gas to light from a Mazda lamp is of the order of 25 micro-amperes per lumen. Figure 9 shows the color sensitivity curves for these cells. The sensitivity curve for Cs-Mag-Ag cell is notable for two maxima, one at about 3,200 Ä and the other at about 8,700 Ä. It is the peak in the deep red which causes its response to be so great for artificial light.

FIG. 9.

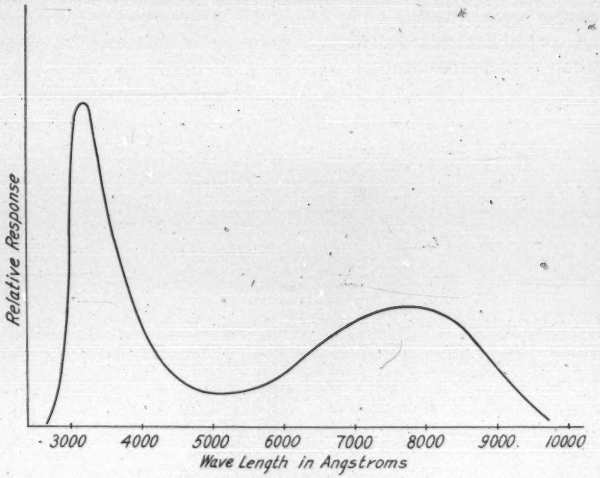

Relative Response
3000
4000
5000
6000
7000
8000
9000.
10000
Wave Length in Angstroms

FIG. 10.

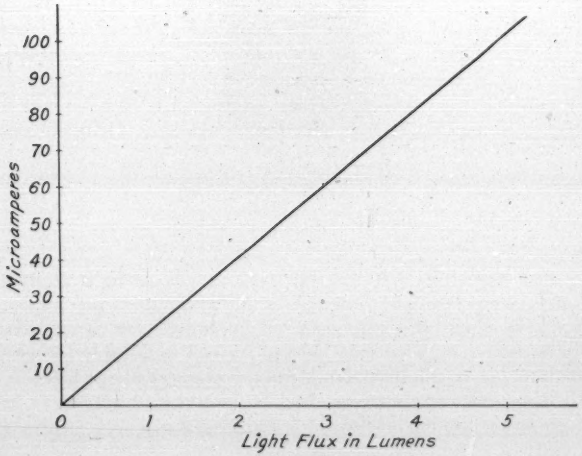
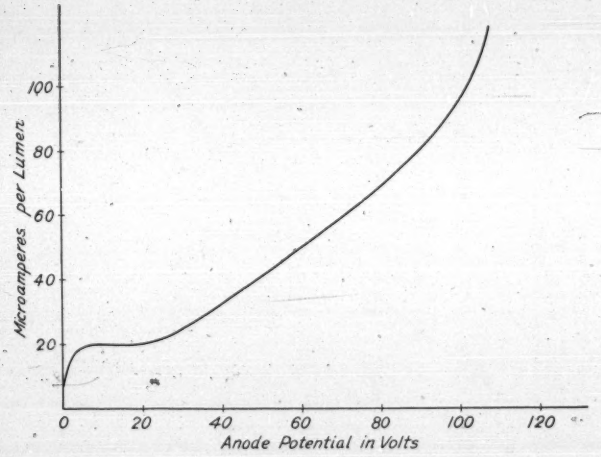

Microamperes
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
Light Flux in Lumens

Figure 10 shows the current illumination curve for vacuum photocell for various illuminations. The relation is a linear one over a wide range, which confirms the first law we mentioned before.

The sensitivity of all these photocells can be considerably increased, without changing their color response, by introducing at low pressure a neutral gas, usually argon or neon. The effect is due to the ionization of the gas molecules by collision with the photo-electrons. Figure 11 shows the voltage

FIG. 11.

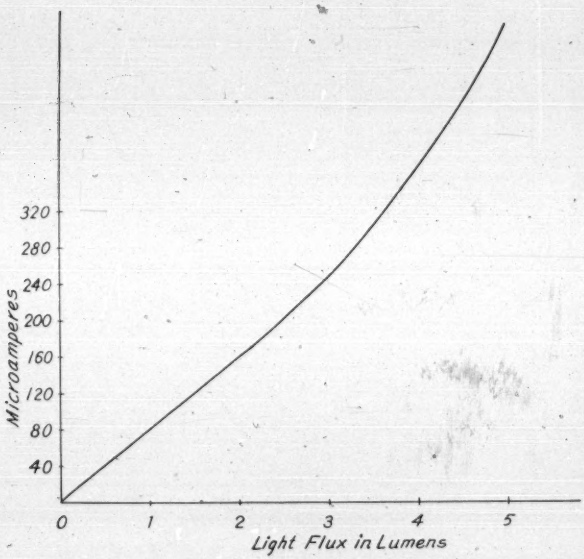


current characteristic of such cells. It is evident that voltage, and consequently this kind of amplification, cannot be increased indefinitely without running into unstable conditions which finally result in uncontrollable glowing of the cell. In practice, this kind of amplification is never carried over 5–6 times. The current illumination characteristic of a gas-filled cell is not as straight as for the high vacuum cell. It is shown in Fig. 12.

Another peculiarity of the gas-filled cell is its nonlinear response to the light of varying intensity, which is of such

importance in most of the practical applications. Figure 13 shows the dynamic response curve for gas-filled cells. As we should expect, the effect disappears at the voltage below the ionization potential of the gas, as indicated by the 15 volt curve. Therefore, every gas-filled cell behaves in all respects as a high vacuum cell if it is operated at low voltage.

FIG. 12.

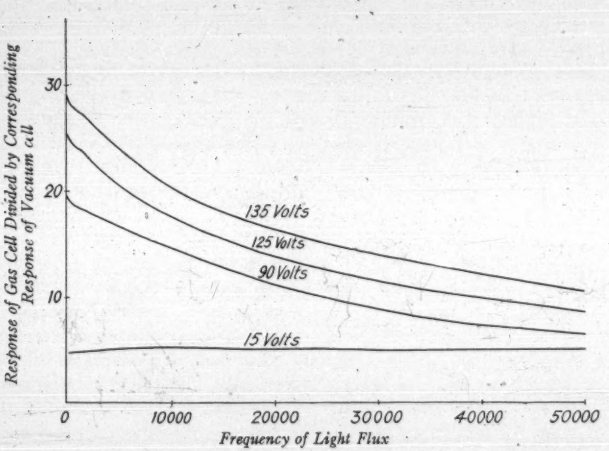


If we compare the color characteristics of the modern photo-electric cells, we notice the high tendency to increase the sensitivity toward the red part of the spectrum. Coming back to the Einstein equation, it means that the work function of the emitting substances lowers.

The method by which this change is accomplished is almost invariably by the application of thin films of alkali metals. Recently, the Research Laboratory of the Phillips

Company, in Holland,[17] published the results of their experiments with such a film, which coincides accurately with the conclusions reached in various laboratories in this country on this point. That is, that the work function can be considerably lowered, at least in the case of alkali metals, if they are formed in the shape of a very thin, probably monomolecular film, properly bound to the conductive surface. In the case of the Phillips cell, this binding medium is a thin film of cal-

FIG. 13.



cium fluoride. In cesium-oxide-silver cells, it is evidently a cesium sub-oxide. If we analyze the condition on the surface of the rest of the newest photo-electric cells, we will find that this requirement of the present mono-molecular film is invariably fulfilled.

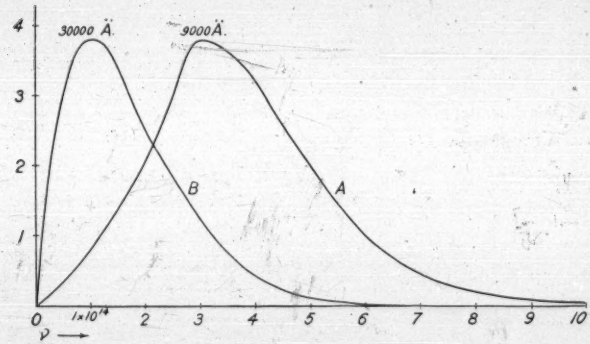
If the cesium-oxide-silver cell is subjected to an electric discharge in a neutral atmosphere such as argon, the sensitivity usually is further increased and the maximum response is shifted back to the blue part of the spectrum. It evidently indicates that the bombardment destroys some of the cesium

[17] J. H. DeBoer and M. C. Teves, *Zeitsch. fur Physik*, 65, 489, 1930.

sub-oxide which releases an additional amount of pure metallic cesium and increases the thickness of the free cesium film. If we carried this discharge on still longer, then the sensitivity would quite rapidly decrease. That would indicate that the cesium film became too thick, so the influence of the underlying sub-oxide is not reaching this surface of the film any more.

It is quite easy to show why this modern trend in the improvement of the photo-electric cell goes over the red part of the spectrum. If we consider the spectral distribution of energy for both sun and artificial light, Fig. 14, we see most

FIG. 14.



of the energy is in the red and the infra-red. In a majority of the practical applications, light is produced by artificial sources, for which the maximum energy emission is in the infra-red part of the spectrum. Curve A on Fig. 14 represents the distribution of energy that is emitted by the ideal black body at the temperature of 3,000° absolute. The relative energy radiated at each frequency is plotted as a function of the frequency. It will be observed that the greatest amount of energy is being radiated at a frequency corresponding to a wave-length of about 9,000 Ä in the near infra-red. The ordinary source of artificial illumination, such as the tungsten filament of our incandescent lamp at the same temperature

gives a distribution of energy similar to that of the black body. It is of great significance to observe how feeble the radiation is for the wave-length shorter than 4,000 Ä, or the blue color of our visual spectrum. But now we arrive at the consideration which is generally ignored, and which is of primary importance in application to this kind of photocell. It has been established that the relation between a radiation and release of electrons is of a quantum nature. Each time an electron is emitted, a quantum of energy of photon is absorbed for the purpose. Now, the size of a photon is $h\nu$, and is obviously a linear function of the frequency. Hence, for a monochromatic radiation of a given frequency, given energy content, there will exist a definite number of photons determined by dividing the total energy of the radiation by the energy of each photon. Curve B of Fig. 14 gives the distribution of photons in black body radiation at 3,000° absolute. It is important to observe that there are relatively no photons in ultra-violet, and that the greatest number of photons are at about 30,000 Ä. Therefore, for the same energy radiated from the source, the photocell whose sensitivity is greater in the red or infra-red will respond better than that whose sensitivity is in the blue. And, therefore, all the photocells whose maximum is greater toward red are better for artificial illumination.

The interest in the photo-electric cell stimulated in the last couple of years by their application in various fields has resulted in intensive work for their improvement. Almost daily, we see in literature both of this country and foreign, the announcement of improvements in this field, but most of the newest achievements are still in the field of the thin films.

Although this paper is primarily concerned with the phenomena of photo emission, it would not be complete without at least a brief reference to photo-conductive and photo-voltaic cells, particularly from the point of practical application. In some cases, these latter cells are competing with photo-electric cells.

The photo-conductive cells are actually much older than the photo-electric cell, particularly its first representative, the selenium cell. This cell was discovered by Smith [18] in

[18] Smith, *Nature*, Feb. 20, 1873.

1873 and since that time up to the present, has been a subject of quite intensive research. As it has been improved now, the best selenium cell is many times more sensitive than the best photo-electric cell. One form of construction of selenium cell is shown in Fig. 15. The action of a selenium cell is based

FIG. 15.

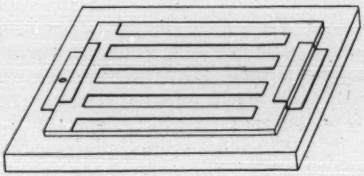
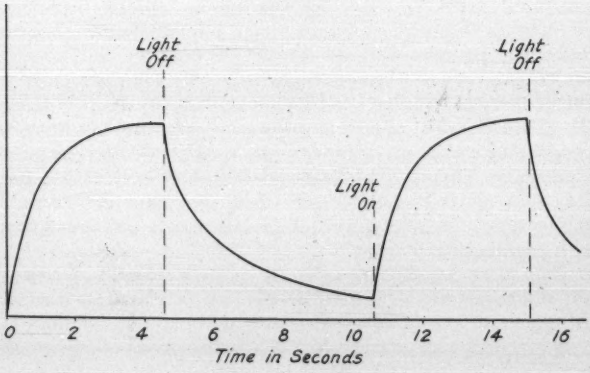


Diagram of interpenetrating electrodes for an illustrative type of selenium cell construction.

on a very different principle from the photo-electric cell, being merely a resistance variation under the action of the light. It is impossible to go into details here, and I will confine myself only to the statement that the limitation of the selenium cell is its sluggishness to the light response. Figure 16 shows its dynamic characteristics. Evidentally with such character-

FIG. 16.



istics, the cell is not very convenient to use where the linear response to the light is desired.

Another cell of the same type is a Thalophide cell developed by Case [19]. It consists of a very thin film of thallium oxysulphide deposited on a quartz plate. The cell operates on the same principle as the selenium, and possesses quite similar characteristics. Its maximum color response is in the infra-red.

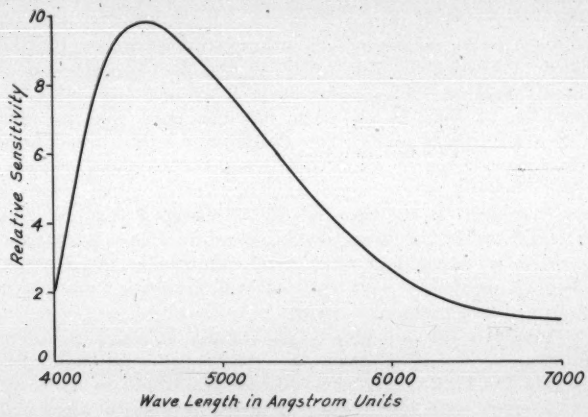
The next type of light sensitive devices whose popularity has come up during the last years is the photo-voltaic cell. One of the best representatives of this cell is the one consisting of copper-oxide cathode and lead anode and diluted lead nitrate electrolyte. The cell is very sensitive and its action, like the selenium cell, is quite sluggish for fluctuating light. Claims have been made by several manufacturers of these cells that they can be made to respond to audio frequencies of light modulation but certainly the dynamic response is much poorer than that of the selenium cell, and cannot be compared with that of a gas-filled photo-emissive cell. There is another type of photo-voltaic effect which is not chemical in nature. W. W. Coblentz [20] has brought attention to the fact that certain crystal molybdenite has the property of developing a potential difference of a few mvs. when illuminated. This type of cell, however, was never improved for commercial form.

As the latest addition to the family of photo-sensitive devices, we should mention the dry copper oxide cell. Although this kind of cell was used by Hallwachs in his early experiments with ultra-violet, it was only several years ago when Dr. Grondahl of the Union Switch & Signal Company, discovered its property for ordinary light. Lately, several investigators, beginning with Dr. Lange [21] and Ruben in Germany, reported enormous improvement in this field; in fact, some of their claims are even astounding. In one of his articles, Lange claims, for instance, the sensitivity of 500 microamperes per lumen. The method of preparation is very simple, and so is the construction of the cell. A thin

[19] Case, *Phys. Rev.*, **15**, 289, 1920; also *U. O. S. A. & R. S. I.*, **6**, 398, 1922.
[20] Coblentz and Hughes, *Phys. Rev.*, **29**, 365 (A), 1927.
[21] B. Lange, *Phys. Zeit.*, **31**, 139, 1930.

plate of electrolytic copper is oxidized at about 1,000° C. in the furnace and the received cuprous oxide surface is etched in acid. The etched surface of copper oxide is provided with a painted, or otherwise deposited, grid-like electrode which serves as an anode. The cell made in that way does not need any battery as it generates its own e.m.f. under the influence of the light. Figure 17 shows the color response of the cell, showing the peak near 4,600 Ä. No doubt, that for many applications, this kind of cell will be a very useful one, but now is too early to prophecy about it. The cell is new and

FIG. 17.



Color sensitivity for copper oxide cell.

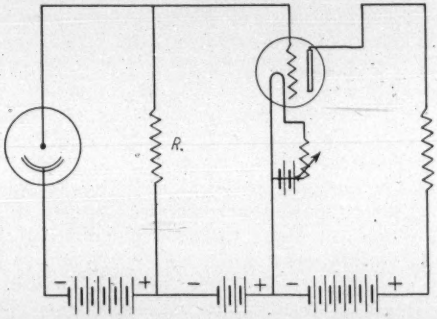
a great deal of work should be done for its final development. One disadvantage is already quite obvious in the present copper oxide cells, and that is its high capacity which ruins completely their dynamic response.

In spite of all the recent improvements, the current delivered by photocells is still too feeble to be used to any practical application directly. Due to the various reasons imposed by the design of practical apparatus, the output of the photocell in most of the practical applications is of the order of one millionth of an ampere, and often smaller than

that. This is the reason why the photocell although known for a score of years started to be used only after the appearance of radio tubes and radio tube amplifiers. By its help, the weak photocell signals are amplified in exactly the same way as the radio signals are amplified in our radio receivers.

The connection of the photocell with the amplifying tube is shown in Fig. 18. It is clear that when the photocell current excited by the light is flowing through the resistance R, it produces a voltage drop across it and changes the potential of the controlling grid. The plate current of the tube varies accordingly, and by the proper adjustment of the circuit

FIG. 18.



follows exactly the variation of the light. The output of the tube is coupled further with a desired number of stages of amplification. Then the photocell current can be amplified to practically any desired value.

The limitation of the amplification is the ratio between the amplitude of the signals and amplitude of the noise developed during amplification. This imposes a certain limit beyond which the photo-electric impulse cannot be successfully amplified.

III. APPLICATION OF PHOTOCELL.

Without a doubt, from a commercial point of view, the most important application of the photocell is to the art of producing audible motion pictures, commonly spoken of as

"talking movies." Beginning only a few years ago, this new industry has already taken gigantic strides to replace the silent screen. The photocell, formerly an insensitive laboratory device for photometric measurements, has been swept along in the rapid development as one of the indispensable organisms of sound projection assemblies, and is now a common article of factory production. When one considers that in the United States alone, there are more than 23,000 moving picture theaters, practically all of which will soon be converted into sound-picture auditoriums, and then thinks of the potential possibility of the demand for hundreds of thousands of sound projectors in the home, one can understand what an impetus photocell development has received.

Although the industry is recent, the idea of sound recording on films is quite old. As early as 1880, Fritts [22] outlined a scheme for photographing audible effects directly on the film, but the idea did not receive recognition at the time. Gradually, the art of recording developed through the contribution of many investigators, until the present highly perfected methods were evolved.

Modulation of light by sound is secured nowadays by several methods. All of them may be arranged to produce one of two types of sound track on the film, (*a*) Variable density, (*b*) Variable area.

In the first type, a track of uniform width varies in opacity along the length of the film. In the second type, the record is of uniform opacity, but varies in width on the track. Figure 19 is a photograph of a portion of the film showing clearly the differences of the track.

Fortunately both schemes involve the use of identical optical systems, and the same scheme of photo-electric reproduction will serve equally well with either kind of film. Essentially, light from a narrow, horizontal illuminated slit is focused into a fine line across the track. Whether the optical density changes as the film moves, or whether the width of the record changes, the amount of light transmitted by the film varies in exact accordance with the original sound and produces corresponding currents in the photocell receiving the light.

[22] Fritts, U. S. Patent No. 1, 203, 190.

Figure 20 illustrates a practical optical system for the purpose.

The actual luminous flux entering the cell is very small and the power delivered by it is only about 0.01 microwatt. Since it requires about 20 watts to operate the loud speakers in a medium sized theater, it may be seen that an amplification of two billion times is necessary; and this overall

FIG. 19

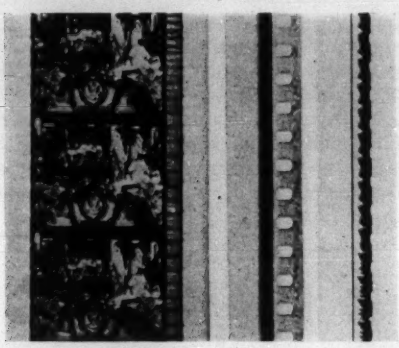
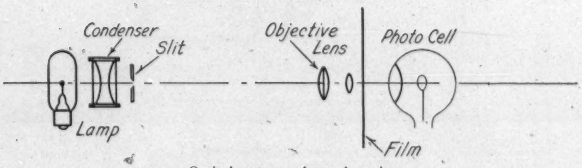


FIG. 20.



Optical system and sound movie.

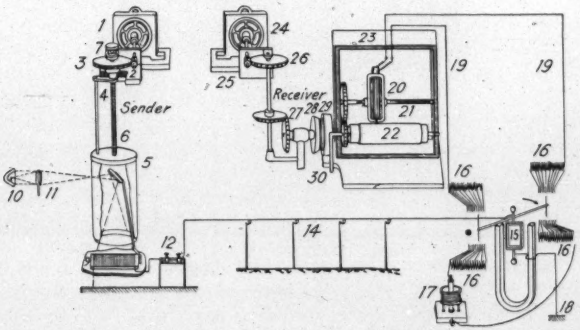
amplification should be linear over a range of frequencies from about 60 to 8,000 cycles. In spite of the enormous amplification, it is effectively handled by the modern tube amplifiers. A transformer coupled amplifier is usually employed in most commercial installations.

The second important application of the photocell is in transmission of pictures. The attempts of electrical trans-

mission of pictures began long before photocells were known. The first significant experiments were performed by A. Bain and F. Bakewell in 1843 and 1848, respectively. Both used for purposes of transmission, a specially prepared picture consisting of conducting and insulating portions and provided means of exploring by an electric contact. Even this crude scheme was perfected to such an extent by Caselli that during the decade of the sixties, it was exploited for a while commercially for transmission over wires between Paris and Lyon, in France.

The electric contact method was ultimately replaced by a scanning system in which a translucent replica of the original picture was explored by a pencil of light. A selenium cell served to transform variations in optical density into corresponding fluctuations of current. This scheme was sufficiently practical to induce A. Korn in 1907 to attempt commercial transmission of manuscripts and pictures over telegraph wires, Fig. 21. However, it was not until the

FIG. 21.



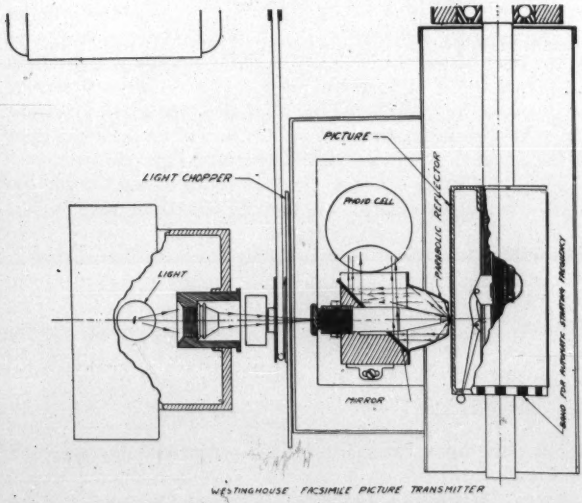
introduction of the photocell that results were obtained comparable to those secured by present-day devices.

There are now two principal methods of scanning. The first method, similar to that of Korn, requires the preparation of a transparent replica of the subject to be transmitted. This diapositive is wrapped about a translucent cylinder upon

whose surface is focused a small spot of light. The light which penetrates the positive falls upon a photocell. By rotating the cylinder, and simultaneously advancing it along its axis, the whole surface is gradually explored. The photocell faithfully responds to every minute change in translucency. A highly developed commercial installation by the Bell Telephone Company [23] in this country, employs this principle for transmission over telephone lines from coast to coast.

Since it is very objectionable in a modern transmitter to necessitate preparation of diapositives, a method of direct scanning of the original has been developed. By this method, only light which has been scattered from the surface reaches the cell and its output is consequently greatly reduced. This implies that the efficiency of the optical system becomes very important. A number of optical arrangements have been introduced, one of which is seen in Fig. 22 as developed by the WEMCO Research Department.

FIG. 22.



[23] Ives, Norton, Parker, Clark, *B. S. T. J.*, 4, April 1925.

The image of an incandescent filament is focused upon a diaphragm *D*. A tiny circular orifice in the diaphragm serves as a secondary source, and a sharply defined image of it is formed by the lens *L* upon the picture wrapped about the cylinder. Surrounding *L* is a parbolic reflector whose focus coincides with the luminous spot. Light scattered from the original is gathered by the reflector into a fairly homogeneous parallel beam which is deflected into the photocell by means of the plane mirror *M*. This optical system with an ordinary automobile headlamp as a source, is capable of producing a current of about 0.05 microampere in a high-vacuum photocell. An amplifier of three stages, using two screen-grid tubes is sufficient to deliver power for the operation either of a receiving apparatus or of the modulator of a broadcasting station.

For receiving the signals, a system almost identical to the transmitter can be used. For this purpose, the scanning source of light and photocell is replaced by another source of light which can be modulated by the signals from the transmitter. If a photographic film is wrapped around the cylinder and the cylinder will rotate and advance exactly in step with the cylinder of the transmitter, and the intensity of the light will follow the signals from the transmitter, we will receive the duplicate of the transmitted image on the photographic film. As a variable source of light, there often is used a glow discharge tube, or an electrically operated light shutter.

There are many other methods of reproducing the picture which involve chemical or mechanical recording devices, but it will be too far from our actual subject to describe them more fully.

For most of the present practical systems, it requires from two to four thousand cycles per second to transmit a picture. Therefore, an ordinary transformer coupled amplifier, similar to the one used for the reproduction of sound in the sound movie or radio, can be used for the purpose.

The time of transmission in most of the commercial installations is from 8 to 1 minute. The following three pictures illustrate the appearance of several commercial facsimile installations. Figure 23 shows the one developed by the WEMCO. On Fig. 24 is one by Belin, and is typical of all

French installations, and in Fig. 25 is shown a complete two-way installation of the German Post Office.

FIG. 23.

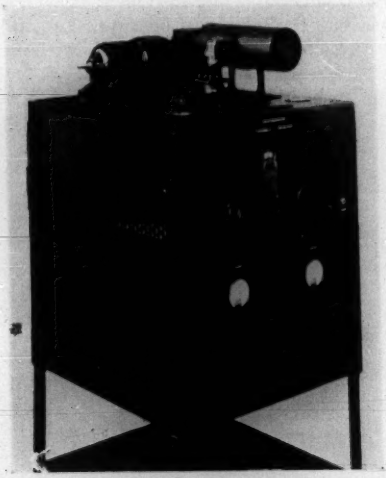
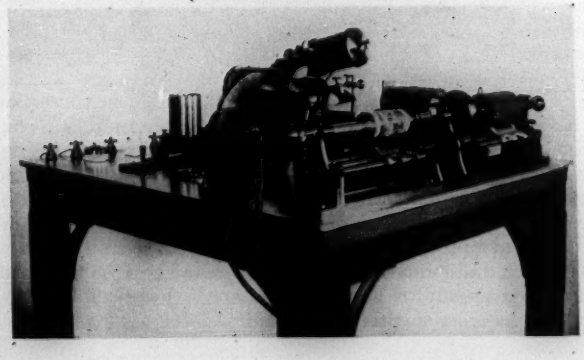


FIG. 24.

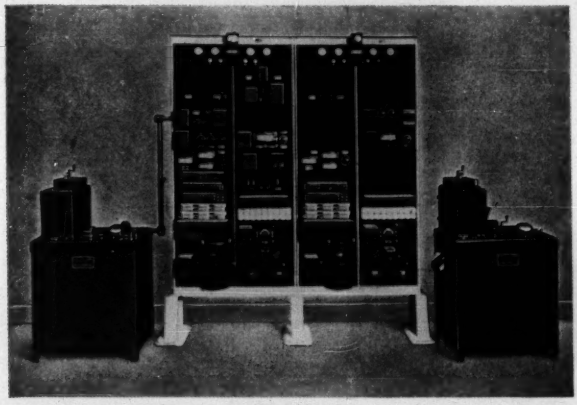


Figures 26 and 27 are fair examples of what modern facsimile actually can transmit over a great distance.

We have stated in effect that both sound movies and facsimile transmission received a great impetus with the advent of the photocell. The statement is even more applicable to television, for television of a quality good enough to deserve the name is absolutely impossible without the photocell.

In a sense, television is simply an enormously accelerated picture transmission, a series of almost instantaneous views

FIG. 25.



of a moving object being so rapidly presented in succession that the eye is deceived due to persistence of vision, and continuous movements appear to be reproduced. The physiological aspects are precisely the same as in the art of moving picture projection. However, the speed with which each view of the object is presented necessitates the solutions of entirely new problems in respect to method of scanning system of optics and process of amplification. The result is that television apparatus as a whole bears little resemblance to that of its more sluggish precursors.

If we assume, for illustration, 100 lines per picture, and assume also that there is equal vertical and horizontal definition for pictures whose edges are in the ratio of 5 to 6, the maximum picture frequency will be:

$$n = 100 \times 120 \times 16/2 = 96{,}000 \text{ cycles.}$$

FIG. 26.

This means that a given transmitting carrier frequency will be modulated plus and minus 96,000 cycles if both sides of the band are used. The band width is, therefore 192,000 cycles or almost 20 times more than at present permitted for broadcasting of music and speech.

The rapid scanning in itself presents a difficult problem. Of all the methods proposed for the purpose, the most common, and perhaps the simplest, is the so-called Nipkow

disc invented by P. Nipkow in 1884.[24] Originally an optical image of the object to be transmitted was formed upon the disc within the two concentric circles bounding the spiral, Fig. 28. The radial distance between the first and last hole determined the maximum height of the image, while the circular distance between successive holes corresponded to

FIG. 27.

the width of the image. A photo-sensitive element was placed back of the disc just opposite the image.

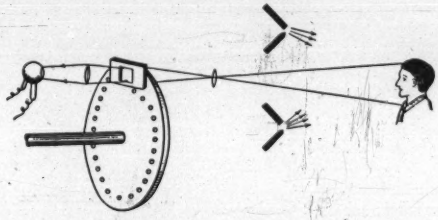
When the disc is rotated, each hole describes a path under the image once per revolution. Just as any one hole finishes its path, the next succeeding one begins one space below. Thus at a given instant light from only one spot of the image affects the sensitive element and produces an electric effect

[24] Nipkow, German Patent No. 30, 105, Jan. 6, 1884.

proportional to the intensity of that spot. In one complete revolution the entire image has been converted successively into a definite series of electric impulses.

When one considers the faintness of illumination produced by an optical image of a non-luminous object and then figures that on the average (for a 100-line picture) only 1/12,000 of the total light flux enters the photo-sensitive device at one instant, and that each element affects the sensitive device only about 1/200,000 of a second when it is represented at all, it becomes evident that even with the modern photocell the problem is almost hopeless.

FIG. 28.



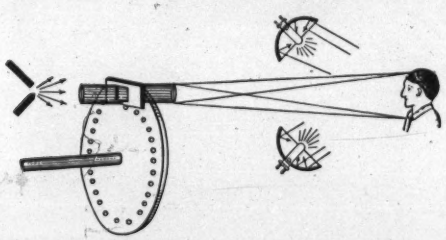
As a way out of the difficulty, it was proposed by A. Ekstrom [25] in 1910 to reverse the system of optics, Fig. 29. Instead of dividing an optical image into numerous elements, he suggested scanning the object directly by means of a moving spot of light and receiving the light reflected from the spot by a photocell placed very close to the object. There are two distinct advantages gained. First, the spot of light may be made very intense by concentrating the radiation from a brilliant arc. Second, a large amount of light may be collected by employing either a very large photocell or else a large reflector with a small photocell.

The combination of the Nipkow disc with the Ekstrom scheme of optics made possible the first practical solution of the television problem and is used extensively even at the present time.

[25] Ekstrom, Swedish Patent, No. 32,220, Jan. 24, 1910.

The photocell plays no part at all in the reception of television signals sent out from a broadcasting station. If a radio receiver designed to pass the proper frequency band is tuned to the carrier of such broadcast signals, the loudspeaker will convert the impulses into a chaos of noisy sounds. If, however, the loudspeaker is replaced by a flat-plate glow tube properly connected, each change in signal will produce a change in intensity of glow instantaneously over the whole area of the plate. To secure the televised picture, it is necessary only to rotate before the glow tube a Nipkow disc provided with the same number of holes as the one used at the transmitting station and to regulate the speed to coincide with that of the sending disc. When these conditions are satisfied, an image will be seen pictured in the glow.

FIG. 29.



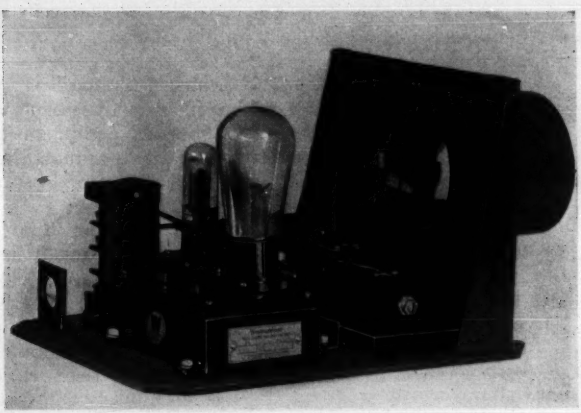
Of course the described system can be regarded only as the first approximation of the solution of the television problem. There are better systems which are now under intensive development in the laboratories.

Within the last half century an endless number of uses for light-sensitive devices have been proposed, but it is only during the last few years that many of the ideas have been practically developed.

Out of the great number of miscellaneous applications of the photocell that have been actually made and that have been recorded in literature, a few are selected examples to serve as interesting illustrations of what distinct operations can be performed.

Doubtless the most common application of the photocell is its function as a contactless relay. In any case where mechanical contact is inconvenient or even impossible, the photocell with accompanying light beam provides an easy solution of controlling operations. In combination with an amplifying tube, the device becomes a sensitive and rugged commercial unit, Fig. 30. The unit serves a useful purpose in counting the number of articles turned out in mass production, persons passing through an entrance or exit, vehicles

FIG. 30.



entering or leaving a tunnel, and so on to the limit of one's imagination.

A similar device is employed together with standard colored lights to control traffic at busy intersections. It is conveniently installed at intersections of main highways with less important roads. In such instances, traffic is always open on the highway unless a vehicle approaches on the crossroad, in which event, an interrupted light beam initiates a relay action to change the traffic lights.

In visual inspection of industrial products, the human eye is not always capable of making close enough selections or

gradations, and the eye becomes fatigued as the day progresses, so that the quality of the results of inspection is much different in the evening than in the morning. Not only can the photocell perform this visual inspection, but it can be made to do it with much greater accuracy and reliability. The inspection of surfaces by either the intensity or the quality of light reflected into a photocell has become a commercial reality. If the article is small or can be caused to travel uniformly under an inspecting beam, the task of detection can be readily performed by the unit already described. When the surfaces are large, some sort of scanning method may be employed or else a bank of similar cells in series may inspect simultaneously an illuminated strip of the moving article.

Matching of colors is a task for which a photocell is inherently suited. Each type of cell has its own color-sensitivity curve which is always constant. Auxiliary equipment is essentially the same as that used in standard color matching devices, but the photocell with a suitable indicator is substituted for the human eye.

With the advent of sensitive photocells which are capable of responding throughout the entire visible spectrum, it has become possible to construct practical automatic color analyzers. An accurate, though rather complicated, analyzer has been designed by A. C. Hardy.[26] Essentially, light from opposite sides of an incandescent tungsten ribbon illuminates a standard surface of magnesium carbonate and the surface of the sample to be analyzed, Fig. 31. Diffusely reflected light from both surfaces is projected in rapid alternation through a monochromator into the cell. An automatic mechanism controlled by the output of the cell records on a drum the ratio of the energy reflected from the sample to that from the standard for various wave-lengths. The device is constant enough to retrace a record without appreciably widening the original pen line, and accurate enough to check Bureau of Standards data for a glass filter. It is independent of the shape of the color-sensitivity curve of the cell.

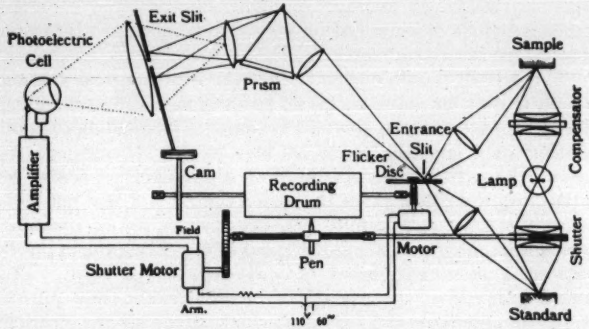
A simpler recording color analyzer, which has the advantage of being portable, has been built by P. J. Mulder and

[26] Hardy, *J. O. S. A. & R. S. I.*, 18, 96, 1929.

J. Razek. In this instrument the sample is placed at the center of a luminous hemisphere, and the reflected light passes through a monochromator to the photocell.

The fact that a cell is ordinarily not flat in color response is used to advantage in both qualitative and quantitative measurements upon colored liquids and solutions encountered in the chemical industries. For example, automatic titration can be controlled by the photocell.

FIG. 31.



The optical system of the color analyzer with a schematic representation of the recording mechanism.

Again, a good illustration of the honorable position acquired by the photocell in important operations is its use for recording the passage of a star over a given meridian and hence for setting the clocks of the world. For this purpose, the cell is placed behind the collimator slit of an astronomical telescope. A hair line is focused in the middle of the slit. When the image of a star comes upon one edge of the slit, the light passing the edge is used to produce a musical note in an auxiliary device connected to the cell. When the image of the star coincides precisely with the hair line, the light and hence the musical note are interrupted. At the same time a photographic record is made of the transit. The accuracy obtained is many times greater than that secured by visual observation.

One can readily see how a photocell may be utilized in recording swings of the pendulum, in a precision clock without in anywise producing a retarding torque.[27]

For integrating the total amount of light emitted by a given source over any period of time, L. R. Koller[28] has developed a unit consisting of a photocell in series with a battery and a hydrogen voltameter. The total quantity of electricity passed by the cell is accurately recorded by the volume of the hydrogen liberated at the cathode of the voltameter. In this way, for example, daily computations may be made of average daylight illumination. Instantaneous values of illumination may also be obtained by using a sensitive recording meter.

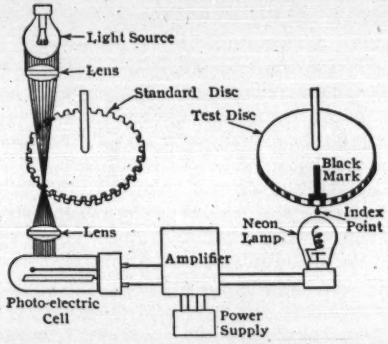
We are all familiar with the nature of an optical grating which is used in many forms of spectrographs for producing diffraction spectra of a given light source. The ruling of good grating such as those made by Rowland has heretofore required the tedious preparation of an almost perfect screw for advancing the ruling point through a precise interval between successive lines. Gramont has designed a ruling machine which is capable of spacing the ruled lines with uniform intervals of a definite number of wave-lengths of light. The machine involves the use of an interferometer, one mirror being mounted on the carriage which supports the grating and the other mirror being rigidly fixed to the frame. Motion of the carriage causes interference rings to precede across a slot in front of a photocell, and a special relay is arranged to stop the motion of advancement after a definite number of rings have passed. The ruling point then scribes a line, after which the carriage again advances through precisely the same interval. Thus uniform grating spaces, equal in width to a definite number of half-wave lengths, are secured without the necessity of an accurate screw.

A clever and precise method for calibrating watt-hour meters is described by Aronoff and Young.[29] A beam of light is focused upon the slotted periphery of the rotating disc of a standard meter, Fig. 32. Thus the light which enters a photocell situated beneath the disc is modulated with a

[27] Ferrie, Jouaust, and Mesny, *Comp. rend.*, 178, 1117, 1924.
[28] Koller, *G. E. Review*, 31, 85, 1928.
[29] Aronoff and Young, *Electric Journal*, 36, 255, 1929.

frequency determined by the speed of rotation. The pulsating current in the cell is amplified and fed into a glow tube which is caused to illuminate the notched rim of the rotating disc of the meter to be calibrated. The number of notches is equal to the number of slots in the standard disc. The calibrating mechanism of the second meter is adjusted until its disc appears to be stationary. Under this condition its speed is precisely the same as that of the standard. It is understood that both meters are supplied with the same energy. Modifications of this ingenious scheme appear to be innumerable.

FIG. 32.



Schematic arrangement of stroboscopic meter testing arrangement.

Another application capable of numerous modifications is the combination of a photocell with a galvanometer provided with a mirror. An arrangement for controlling furnace temperatures can be found in an article by Arnold.[30] A thermocouple in the furnace produces a definite deflection of the galvanometer so that its mirror reflects a beam of light in a definite direction. A photocell is placed so that any further deflection of the galvanometer sends the light into the cell and activates a device for controlling the heating current or fuel supply. By using two photocells in opposition and adjusting the beam initially to illuminate both equally, a double-acting control may be obtained.

[30] Arnold, *Radio Engineering*, 9, 30, 1929.

One of the earliest uses to which photocells were put was in safety devices for smoke detection and fire prevention. A cell, conveniently located in a building so as to be properly shielded from excess daylight and artificial illumination, is capable of detecting spurious radiation from a starting fire and can be caused to operate an alarm or extinguishing apparatus. For smoke detection, a beam of light is directed into the cell through the space to be protected. Any smoke arising will obscure the light and change the output of the cell, which can in turn operate a relay.

Exactly the same device can be used as a burglar alarm, in which case the beam is interrupted by the passing of a human body.

Other safety device applications, such as the stopping of machinery when a danger point is reached or when a break occurs in some part, will suggest themselves.

A most interesting accomplishment made successful by the photocell is the communication of intelligence over a directed beam of light. As a matter of fact, a beam of light, modulated by the human voice and detected by a selenium cell, was actually the precursor of modern telephony. Graham Bell experimented with communication over light prior to his invention of the wired telephone. In recent times, the same scheme improved by the substitution of a photocell and amplifier for selenium cell has presented a convenient means for telegraphic, telephonic and facsimile transmission over short distances. The greatest distance over which intelligence may be transmitted depends only on how far a modulated beam can be optically projected with sufficient intensity to energize a photocell. Practical use has been made of light-beam transmission for military communication at sea.

A valuable modification is to employ an invisible radiation either of ultra-violet or infra-red. Infra-red is of particular promise as a medium of transmission, because of its ability to penetrate fog, smoke, or dust better than radiation of shorter wave-length. Modern photocells, such as the cesium-oxide cell, which have a peak of sensitivity in the near infra-red, are quite suitable as detectors of these radiations.

Recently success has been claimed by Baird [31] in the trans-

[31] Baird, *Television*, 2, 337, 1929.

mission by television of objects illuminated only by infra-red radiations.

As a final illustration of the many rôles played by the photocell in the service of humanity, we wish to describe briefly a reading device in which a photocell is the substitute for a human eye. In 1914, Fournier d'Albe [32] invented an instrument which actually made it possible for a blind person to read by the use of his sense of hearing! The operation of the device, which d'Albe called an "optophone," is based mainly upon the reception of a photo-sensitive element (originally a selenium cell) of light scattered from a printed page, much in the same manner as described for facsimile transmission. Figure 33 gives a sketch of the optical system

FIG. 33.

by means of which the page is illuminated. A light chopper containing five concentric circles of holes, each circle being perforated with a different number of holes, divides the light into five separate beams. These beams are focused into five spots closely arrayed in a straight line along the height of the printed characters. As the page is moved sidewise, the spots of light, each of a different frequency, effectively peruse the printed line. In a white space all five spots reflect light to the sensitive element and produce a current composed of five frequencies which ultimately cause a composite tone in a set of phones. However, when the spots are partly absorbed by the black characters, the tone in the phones changes in a manner peculiar to the particular letter being scanned. Within a period of a few months, a blind person may be taught to read common print at a rate as high as sixty words a minute.

[32] d'Albe, *Moon-Element*, p. 94, 1924.

Occurrence of the Pellagra-Preventive Vitamin in Liver Extract. Experiments made on dogs by JOSEPH GOLDBERGER AND W. H. SEBRELL (Public Health Reports, 1930, *45*, 3064–3070) indicate that liver extract is a fairly good source of the vitamin which protects from the occurrence of pellagra, and should be of value in the treatment of that disease.

J. S. H.

Vitamin C Content of Tomatoes. BERTHA CLOW AND ABBY L. MARLATT (*Jour. Agric. Research*, 1930, *40*, 767–775) have used the recovery dosage method to measure the vitamin C content of tomatoes. Field ripened tomatoes, canned by the cold-pack method, retained the antiscorbutic value of the raw tomatoes for 9 months, but suffered a slight loss in value at the end of 15 to 20 months. The open kettle method of canning decreased the antiscorbutic value. Greenhouse tomatoes were of less value than field tomatoes as a source of vitamin C. The content of this vitamin increased with the maturity of the tomato.

J. S. H.

New Reaction of Ferrous Ions. ROBERT HILL (*Proc. Royal Soc.* 1930, *B 107*, 205–214) states that an intense red complex ferrous ion is produced by the addition of $\alpha\alpha'$ dipyridyl to the solution of a ferrous salt within the pH range 3.5 to 8.5. The reaction may be used for the quantitative measurement colorimetrically of both ferrous and ferric iron, by determination of the intensity of the red color both before and after the addition of a suitable reducing agent, such as true sodium hyposulphite, which reduces ferric ions to the ferrous state.

J. S. H.

THE WEALTH OF NATIONS, WITH ESPECIAL REFERENCE TO THAT OF THE AMERICAN PEOPLE.*

BY

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In appearing before you as an engineer, an economist and a statistician my attitude is one of humility. I have come to abhor the terms statistics and statistician. I sense that in the public mind they are becoming associated with the terms magic and magician, and are acquiring a disrepute for which the professors of the art of forecasting are responsible.

Statistics means simply a numerical expression of knowledge, which may be conveyed more concisely in figures than in words. The essential thing is the knowledge. This has nothing to do with crystal-gazing.

In economics we have become confused by many theses and hypotheses. There are some fundamentals to which we may revert and from which we may hesitate to wander far. We may feel safe in considering the working of supply and demand as being as certain as the law of gravitation, but when we approach the subject of money we find a controversy that has been running for 300 years without yet being settled.

The late Lord Melchett, when he visited us last summer, remarked that there is need for more psychologists and fewer economists. Paul Warburg, the eminent banker, was more specific in saying a few weeks ago that in his view the so-called "business cycle" forms a subject of study for psychologists rather than for economists. So it appears that economists are also falling into disrepute.

As an engineer I feel more comfortable. I do not anticipate that the engineer will ever be regarded as superfluous.

* Presented at the Stated Meeting held Wednesday, March 18, 1931. The annotations of lecture were omitted in the original delivery.

The training of the engineer is toward the ascertainment of facts and the weighing and measuring of them. His general attitude in life is thus dominated. The association of the capacities of statistician, economist and engineer is not heterodox. Of the three professional elements, however, the engineering is in my mind preëminent, and the thoughts that I may hereinafter express to you will probably appear to you to have that coloring. Anyway, I shall be inspired by engineering pragmatism rather than any emotionalism.

In selecting the title for my address to you this evening I have taken that of the primitive work on economics with which most persons are familiar, but while I shall conform to its simple elements of thought I shall naturally express quantitatively many things that formerly could be conveyed only in essence. I shall be elemental in many ways and even risk wearying you with economic arithmetic when you may be expecting a dissertation of the grade of quaternions or of relativity, which I frankly confess is above me.

Yet every day I read and hear so much economic misunderstanding on the part of financiers and publicists who ought to know better; and of politicians from whom perhaps no more ought to be expected; that I yield to the temptation to be simple.

In approaching many economic subjects I find it useful to think of the affairs of a family and consider that the affairs of the American people as a whole may be something similar multiplied by 30 million; or of my home community multiplied by six hundred thousand, the population of my town being small. So too do I find it clarifying in respect of my present subject to review the early economic history of the colonization of Massachusetts, 300 years ago. I refer to Massachusetts only for the reason that I have studied its affairs somewhat, and I have not done so in respect of New York, Pennsylvania and Virginia.

Our forefathers, including my own, came from England to Massachusetts with mixed motives. Some came seeking religious freedom. Others came mainly for the sake of economic betterment, just as their descendants began after the Revolution to move westward. But whatever were the motives their economic problem was the same.

The immigration which ran strongly from 1630 to 1639 brought to Massachusetts some of the most virile stock of England. The newcomers were disappointed in the severity of the winter and if they had been better informed they might have directed themselves further south. Nevertheless, they found the opportunity that they expected, the relative ease of their economy being evinced by the rapid multiplication of their families and their increase in wealth.

This is not to imply that they did not have to work long and hard, shivering in winter and sweating in summer. The breaking up of virgin soil with primitive tools, the felling of trees, and the pulling of stumps and boulders were back-breaking tasks. However, the farms, the forests, and the fisheries had it in them to supply all of the food, fiber and fuel that was needful for sustenance, clothing and heating. The forests also supplied the timber for habitations, while clay-beds furnished the material for brick, oyster shells for lime, and the skins of animals could be tanned to leather. All of those trades were instituted forthwith. The great deficiencies were cordage, soap, ammunition and tools and implements, which last are generalized under the head of the metals, especially iron. They boldly essayed to make iron at Lynn, using bog ore, but the ore was scarce and poor.

They did not have any gold and silver for money and for currency they used musket balls, or more commonly wampum or shell, which was adopted from the Indians and was legal tender until 1661. They had no banks nor bank accounts. Their increase in wealth could only take physical expression, e.g. in land and houses, cattle, and other live stock, tools, clothing and furniture. In that way the inventories of yeomen dying after 20 years in the new country were often substantial.

They built ships out of their forests, as early as 1631, and the only commodity whereof they had a surplus, being fish they instituted an export trade in it. Vessels with fish went to France and Spain. With the proceeds wine and olive oil were bought and carried to England, where they were sold, so that the ships returned to Massachusetts with metal goods and the other things that the colonists were unable to provide for themselves; or such things that they could buy more easily than they could produce them.

During the first two decades land was of little value. It was of value only as a place on which to live and to produce. John Humfrey, a promoter of the company, acquired an area of five square miles and ruined himself. A house, a windmill or a boat, on the other hand was real wealth. We look back 300 years and visualize this primitive colony creating wealth by the application of work to materials, painfully and slowly, but ever forging ahead. If they had had credit, which means the ability to borrow from abroad tools and implements, metal goods and other commodities they might have progressed more rapidly. Even after 20 years not half the farms had a plow.

But instead of looking backward we may turn our eyes to what is now going on in Russia. Do not for a moment entertain the thought that I look with anything but abhorrence upon its economic conception and political system. We are bound, however, to recognize that the Soviet regime, without any gold or any foreign credit worth mentioning, is creating internal wealth in the form of houses, mines, factories, railways, hydroelectric power plants, mechanicalized farms and forests, out of work and materials, and that complaint is made of insufficient labor. I shall wander too far from my subject if I allow myself here to enter into a discussion of the political economy of the Russian program or its prospective outcome. It is sufficient for my present purpose to point out that the Russians are aiming to do in a few years and on a gigantic scale what we have done in 300 years, which would be a preposterous conception if allowance were not made for the advantage of 300 years of science and engineering, and at least they are accomplishing something.

Antithetically we may turn contemporaneously from Russia to France. Prof. André Siegfried, who is well known to us from his astute analysis of American life, has more recently presented us with an estimate of his own people, offered with charm of reason and felicity of expression. The French are a nation of individualists—peasants, artisans, bourgeois. If we accept his definition of bourgeois as "one who has reserves," it is evident to any observer in France that this represents a very large part of the nation. On any

estimate of the national wealth and the national income it must be obvious that the average of these reserves is relatively small.

As though there were some inherent magic in the conception, it is the dream of millions of Frenchmen to acquire a small property, to build a small house, to own a small business, to amass a small private income.

It is the outcome of incredible toil. It makes the individual solitary and unsociable. He calculates even in the most intimate details of his life and affairs. He is without illusions; he has an irresistible desire to work. Toil is an end in itself and the soil a religion.

With that French spirit we may associate the rapid recuperation of France from the war. Anyway it is clearly understood, both in individualistic France and in communistic Russia, that the creation of wealth springs from work. Our own forefathers also understood that, but in the tenth generation from them, we together with those whom we have amalgamated with us have become more or less blinded, dazzled by the results of the superlative bounty of our natural resources and our genius for exploiting them.

My illustrations, historical and contemporary, are sufficient to elucidate a fundamental conception. Wealth is not synonymous with capital, which means the equipment wherewith to produce wealth; nor credit, which means the ability to obtain loans, for which the security may be wealth; nor money, which is the medium for the exchange of goods and services. Wealth is the possession of things, tangible or intangible, that are useful or prized, and is cumulatively the measure of the difference between production and consumption, subject to the subtraction of decay and destruction. I am conscious that my definition is vulnerable. I have avoided introducing the substantive material for we have things devoid of body that are unquestionably wealth. I once participated in the purchase of a newspaper for a large sum of money that possessed physical property in amount no more than 1 per cent. of it. I am doubtful of the adequacy of my qualification "useful or prized." We might put immense labor into building pyramids without their being either. The Egyptians may have had a different opinion.

I do not know if their bankers ever granted credit on the security of a pyramid. Wealth may be lost otherwise than by decay and destruction. By becoming useless and unprized, for example. Perhaps I have gone far enough in self-criticism of my definition. I feel that you will not hold me meticulously to account.

Anyway, I hope that I have made it clear that bank accounts, deposits in savings banks, investments in life insurance, and some other things that are often cited as evidences of wealth are not so at all. They are rather evidences of credit by virtue of which wealth may be acquired and so they may reflect something as to the distribution of wealth. Increase in savings bank deposits does not necessarily imply that the nation is becoming richer, but that may show that the position of the class of people that so entrusts its savings is improving. Even less meaningless are the computations of quotational values of securities purporting to show that the people have gained or lost many billions of dollars in the course of a year, or perhaps in a month. In an inventory of the national wealth none of those items appear in any way. On the contrary the listing is confined to such entries as gold, real estate, cattle, mines, factories, railways, ships, stocks of goods. I have not tried to be completely enumerative, but only to give the idea. So much for the internal position. To this must be added the external, i.e., our investments in other countries and the debts they owe us less what we owe to them and their investments with us.

If we could have such an accounting every year we would have an idea of how we stood in our national economy, just as the thoughtful person periodically weighs his private position. Most of us have no difficulty in doing that, although all of us may need an auditor to dispel our illusions. The corporation does the same thing with the assistance of an auditor, but then there is real need for an engineer's review. The accountants scrutinize and criticize book entries, but the engineer examines things and often finds that book credits remain for property that has vanished or for entire plants that have become valueless by obsolescence. I have had occasion to value a corporate property running to 30 million dollars comprising land, mine, railway, steamships,

docks, and what not. The property of the American people is of the same order, but far more varied, and perhaps ten thousand times as great. Manifestly, no physical survey would be practicable. We have seen what the Interstate Commerce Commission has done in trying to value the railways of the country and they come to no more than a tenth of our total wealth. Yet it has been possible at intervals to make more or less satisfactory estimates by broad deductions and generalizations. The bigger the problem the less desirable is meticulosity. In surveying a forest it is unwise to try to count the leaves, or even the trees.

The conception of estimation that I have intimated hereinbefore—I will hardly say outlined—appears to be the only one applicable to American conditions. Economists in other countries have estimated, occasionally, not regularly, their national wealth in other ways. Their problems may be easier. I do not know. At all events the Canadian government makes such an estimate. German authorities have done it for their country and Sir Josiah Stamp now and then makes an estimate for Great Britain. Inevitably the subject is so complicated that no foreigner may reasonably be critical. Anyhow we are ever prone to accept the printed word or figure as fact, and at the most we may remark, thinking of Great Britain, that Sir Josiah is a competent authority and let it go at that. In respect of our own affair, on the other hand, we may be not only critical but also controversial. I am of course referring especially to experts who believe they know something about the subject and not to journalists who do not. In the matter of the railway valuations, as you know, the Interstate Commerce Commission and the railway companies have differences of opinion and controversies that are a good deal more than academic.

By Act of Congress the Bureau of the Census was long ago directed to make a reckoning of the national wealth every 10 years and this has been done and constitutes our only prolonged record in respect of this subject. Fine drawn conclusions should not however be made from these findings. Congress is prone to prescribe impossible tasks without knowledge of their nature and this is one of them. No one knows better than the Census authorities the pitfalls in

trying to reckon national wealth by the tabulation of returns and they would be thankful to be relieved of this assignment; but encharged with it as a duty they have done the best they could. I warn you, however, against any belief that the wealth of the American people increased from 1912 to 1922 to any such degree as appears from the Census figures, although such an increase has been made the subject of many serious conclusions. The trouble is largely with dollars.

I have previously explained, and I hope I have made clear, that our wealth takes such forms as houses, railways, factories, etc. We may make periodic comparisons of such things, kind by kind, and come to a conclusion, for example, that we are having more or less floor space per family, or more or fewer automobiles. We cannot, however, add together farms, cattle, locomotives, automobiles, ships, etc., and get any reasonable total. In order to do that there must be a common denominator, and that can be only the dollar equivalent of each kind of thing. Obviously alteration in the exchange rate between dollars and things may disqualify a comparison of dollar totals for 1910, 1920, and 1930. We might of course obviate that by adopting arbitrarily a basic dollar, or rate of exchange, e.g. that of 1913, which is now commonly adopted as the base for the computation of indicia of prices. In fact the two conceptions would be precisely the same.

In a book that I wrote nearly ten years ago I offered estimates of the wealth of the American people as of the end of 1916, just before we entered the war, and at the end of 1920, when we had demobilized. I proceeded in accordance with engineering conceptions, surveying our physical possessions, naturally in a bold and rough way, writing off what appeared to me to be useless, e.g. the major part of a great national investment in ships, and computing for both dates in terms of dollars of 1913. In this way I estimated our internal physical property at about 273 billion dollars at the end of 1920 compared with about 268.5 at the end of 1916. At the same time I reckoned that we had gained apparently 17.8 billion in our external position, but expressed the opinion that our holding of foreign internal bonds would probably have to be written off as a loss and that the foreign national

debts to us would have to be scaled down. Both of those forecasts proved to be correct, as of course you know. My thesis was that while the people of the United States gained somewhat from Europe in 1915 and 1916, the gain was much less than popularly supposed and was lost by us in 1917 and 1918; and that our gain in wealth in the decade ending with 1920 was less than it would normally have been if there had been no war. Apart from any statistical finding or engineering survey I think that such a conclusion is in harmony with common sense. Rome acquired wealth by laying tribute upon the whole world then known, and so did Spain by the conquests of Mexico and Peru. General warfare under the conditions of the 20th century, however, is no way for anybody to get rich.

In a rough way I carried my estimate for 1916 back to 1912 with the finding of about 230 billion for that time which was much higher than that of the Census. On the other hand the Census reported for 1922 a figure that looks grotesquely in excess of mine for 1920. Analysis reveals, however, that the Census total for 1922 was in close agreement with mine for 1920 except in respect of the items of chattels and stocks of goods which I reckoned at 1913 values while the Census computed them at current prices.[1] This will explain to you the great variations in estimates of this nature that from time to time may have come to your attention. A little later in my lecture, when I shall essay to give you an estimate for 1929 I shall make myself more clear.

Obviously there is something to be said in favor of each expression of valuation, which may be described alternatively as the physical and the fiscal; or the basic and inflated. After all, it is not the dollar of 1913 that concerns us now, but rather the dollar of 1931. If we could have computations of our national wealth in both ways using the dollar of 1913 as merely common denominator to compound quantities and the current values to reflect contemporaneous positions there would be more clarity. In other words we need two parallel columns of figures. Alas! statistical science is still incompetent and what we get is confusion.

[1] This was discussed by me in an article in *The Iron Age*, May 15, 1924.

In respect of property there are several principles of valuation, the application of which is controversial and has frequently become the subject of judicial decision. For capital goods, i.e. those that may be used for the production of wealth the commercial thought is a capitalization of earning capacity, which naturally is ever changing, wherefore are there fluctuations in a liquid market, e.g. the stock market. For such property there is not only never-ending fluctuation in earning capacity but also in the rate that is satisfying. Consequently there are two variables.

There is some kind of property, however, upon which the rate of return is limited by legislation or even governed by a fixing of price for the product, e.g. public utilities and other non-competitive affairs. Then it may be that the return is not the instrument of determining the value, but oppositely that the value is the factor for determining the return. Then shall that value be original cost, or reproduction cost, or either of them less depreciation, or a complex of all of those thoughts, and perhaps some others?

We may begin to appreciate the difficulties of estimating the national wealth on either a physical or a fiscal basis, and how different two such estimates may be. In respect of the physical basis there is the great question of enumeration, while in respect of the fiscal basis there are constant fluctuations, and of a character so confusing that it is impossible to determine the position of a people.

Let us think of recent events in our own economy. During the last 18 months the quotational value of the securities listed on our exchanges has shrunk by many billions of dollars. Yet our physical property has not shrunk at all, even may have increased. The only shrinkage is by decay or dismissal owing to obsolescence when there is failure to replace it. Nevertheless, when securities were quoted at $200 per share loans were negotiated with them as collateral on that basis, and a decline in price to $100 per share, or less, compelled a liquidation that shook our whole structure. Similarly did the decline in the value of silver have a profound effect upon the economies of the Orient.

Even in the valuation of industrial property similar complications are constantly arising. A concern has a plant

that cost, let us say, $4,000,000 to build in 1913. In 1923 it had no earning capacity, and if that condition were going to continue there would have been no value. A reproduction cost at the time might have been $7,000,000, but of course no one would reproduce such a plant if it were not going to have earning capacity. Five years later it acquired good earning capacity, with prospect for its maintenance, and was valued at $10,000,000 as a going concern. At the same time the same company had other properties in operation but not earning anything or having any clear prospect of doing so, yet were rated as having substantially sound values.

The last condition obtains not infrequently in respect of real estate. There are throughout the country many tracts of land that are assessed at a certain valuation for the purpose of taxation, which are frequently bought and sold at such valuations, on which banks will even lend money, although the land may not have any earning capacity that can clearly be discerned. Perhaps such ownership gives a certain satisfaction to the proprietor. Perhaps there is a potentiality of earning capacity. Anyhow, there is value so long as people are willing to buy and sell.

This leads to the further thought that earning capacity is not the only determinator of wealth. The wealth of India consists largely of the hoard of silver, estimated at 7,000,000,000 ounces, which the people have acquired in the course of time, exchanging their work for it, just as some American people have been exchanging some of their work for diamonds. In an inventory of national wealth silver and diamonds would naturally appear. The American people are supposed to have something like three billion dollars in precious stones, chiefly diamonds. If something happened to cut in half the value of such possessions many persons would be seriously affected. So it is with the people of India and China with their silver.

In any estimate of national wealth time is a highly important factor. This follows from the actuarial principle that a property whose earning capacity will not begin until after the lapse of 30 years has no present value. After that date interest charges consume the yield. Disregard of this principle leads to such illusions as obtained in a recent attempt to

create a scandal out of the oil shales of Western Colorado, which may have producing value in the distant future, but a present value that is negligible. Similarly did Dr. Hjalmar Schacht, who recently visited us, allege that Germany was deprived of 20 billion dollars of wealth through the loss of its colonies by the Treaty of Versailles, implying an immediate loss of one billion dollars of annual income, which is rather preposterous. In just the reverse are the frequent allusions to our purchase of Alaska for a song.

On the other hand the actuarial principle is not entirely valid, or at least it is subject to qualifications. A deposit of iron ore that is useless until after 30 years may not have any present value in the capitalization of earning capacity, but the U. S. Steel Corporation, for example, expects to be doing business 50 years from now and rejoices that it possesses the ore reserves that insure its raw material for doing so. In a time of commercial distress, such as we have recently been suffering, a copper mining company may omit depletion charges on the assumption that it is producing out of its 31st year of ore on which depletion does not need to be figured (which may be more or less of an actuarial fallacy). Instances may be multiplied from the status of coal lands, and other things.

The wealth of any country increases by the amount of its surplus of income over its living expense, i.e. its use of consumption goods; or oppositely, decreases. Previous to the Great War the wealth of the American people increased about five billion dollars a year, which was about 15 per cent. of our income. This was expressed chiefly in houses and railways. Since the war our income has been increasing more rapidly in terms of dollars, partly by virtue of increased population and increased productivity per man, and partly by expression in inflated dollars. On the other hand our living expense has increased by virtue of more desires, and it is doubtful if our percentage of saving has been as high as formerly.

The expression of our savings has also experienced a change. We have put proportionately less into houses and railways and more into public utilities, into new forms of production (such as petroleum and automobile manufacturing)

and into foreign investments. The aggregate of the last has risen to about 17.5 billion dollars, against about 10 billion at the end of 1920.

I have previously referred to my estimate of an internal wealth of 273 billion at the end of 1920, in terms of dollars of 1913, and of the substantial agreement of the subsequent Census estimate for 1922, when reduced to the same basis. In the nine years ending with 1929 the national income has been about 364 billion in terms of 1913 dollars. If I estimate a national saving of 10 per cent., which may be outside rather than inside, the internal national wealth at the end of 1929 may have been about 310 billion. To convert into contemporaneous dollars multiply by 1.7 for 1921 and by 1.8 for 1929, thus obtaining totals of about 464 billion and 558 billion respectively. So you see if you take 230 billion in 1912 as a starting point it makes an enormous difference whether my physical figure of 310 for 1929 or my inflated figure of 558 for the same year be used for comparison.

Of course you must recognize that my estimates for 1929 are but rough. The quantity of our national income is fairly well determined. As to it, there have been annual estimates by the National Bureau of Economic Research, the National Industrial Conference Board, and myself for a long series of years, each employing a different method and we have been in remarkable agreement until recently. I am now using the arithmetic mean of these three estimates. In respect of the scale of general price level, which is represented by the factors 1.7 and 1.8 there is substantial agreement between Mr. Carl Snyder and myself. My reckoning of the percentage of annual saving is purely a guess. I made some study of that subject several years ago, but none recently.

I suppose a reasonable estimate of our national wealth at the present time is somewhere between 310 and 558. That is a wide range, and we may narrow it in a guess of 400 to 450, but that is only a guess.[2] Some real estate is still assessed

[2] Since the delivery of this address, the National Industrial Conference Board has published an estimate of 84 billion dollars (compared with mine of 83.4) for the national income in 1929 and of 361.8 billion dollars for the national wealth, both figures in terms of current dollars. The estimate of national wealth is less than my own rough indication, but not seriously out of harmony, considering the

at 1913 value, but the tax rate upon it has been increased three-fold, more or less. Many houses have been built at inflated costs during the last 10 years and they have established a rental value to which older houses have been written up. It is in respect of such things that deflation makes us squirm and suffer. The stocks of goods that constitute a substantial part of our national wealth at all times, normally about 10 months supply, we think, or perhaps 60 million dollars worth, are of course correctly reckoned at cost or market, their turn-over being rapid.

Turning away from our own position, we have an interesting comparison in a recent estimate by Sir Josiah Stamp in respect of the national wealth of Great Britain. In 1914 he calculated it at £14,319,000. In 1930 he reckons £24,445,000,000 gross, less £6,400,000,000 indebtedness, leaving £18,045,000,000 net. Sir Josiah summarizes that Great Britain spent the whole of its national savings for about six years following 1914 and lost 25 per cent. of its foreign investments. During the next eight years there was a saving, and therefore an increment of wealth, of approximately £450,000,000 a year.

I infer that Sir Josiah reckons in current sterling and I entertain some doubt whether the wealth of Great Britain in 15 years increased from 14 to 18 on a physical basis, in spite of its war losses. I do not venture to go far in criticism, for I recognize Sir Josiah as an eminent authority, who knows vastly more of his subject than a foreigner possibly can. Moreover, I may observe that while the wealth of the United States is mainly internal, that of Great Britain is largely external, and any physical estimation of that form of wealth is extraordinarily difficult. We may for example lend a billion dollars to Germany and enter that sum as a credit on

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complexity of the subject. A sidelight has become available in a recent estimate of about $230,000,000,000 as the aggregate of fire insurance risks in 1929 compared with about 150 billion in 1920. These data tend to support the higher estimates for the national wealth, for of course there is much of the latter in land, in mines, roadbeds, etc. that are not covered by fire insurance, while the coverage on other forms of property is seldom 100%.

our books without being able to estimate the physical property into which it is going to be converted.[3]

It has been competently computed that the quotational value of stocks listed on the New York Stock Exchange fell from a total of 81.5 billion, Sept. 1, 1929, plus 4.3 billion of new stock issued subsequently, to 45.6 on Dec. 1, 1930, a shrinkage of 40.2 billion. At the same time those listed on the New York Curb Exchange shrank $15,000,000,000. It has been estimated less reliably that the shrinkage of all American corporate stocks, not including bonds, was upward of $75,000,000,000.[4] These, or similar, figures have been cited as showing the staggering loss suffered by the American people during the depression of 1929–31. It must be clear from my exposition hereinbefore that they do not really have any such meaning, although they are interesting in other ways. Nor are they properly to be compared with any estimate of the national wealth, either physical or fiscal, meaning basic or inflated. Neither of such estimates take into account what I have elsewhere described as intangible wealth. Moreover, in summarizing security values there is obviously a good deal of duplication, through one company holding the stock of another and both being listed.

By intangible wealth I mean such things as goodwill, organization, patent rights, trade marks, operating experience, etc., which, without possessing any body, have earning capacity and consequently commercial value. I have previously suggested an instance of this kind in respect of newspaper publishing. As regards the value of useful patents I need not elaborate. The importance of organization and operating experience is not popularly appreciated but we know that it constitutes a large part of the value of many corporations. An individual conducting business may be

[3] The recent estimate of Sir Josiah Stamp was the subject of his presidential address to the Royal Statistical Society, Nov. 18, 1930. The inventory method that we use for America, which has its complexities as I have herein explained, is impracticable for Great Britain. Sir Josiah estimates essentially on the basis of capitalization of income, but he introduces entries for real estate and for chattels that are essentially of inventory nature, without going into details.

[4] The quotational value of all corporate stocks in the United States in the summer of 1929 is supposed to have been of the order of 150 billion dollars.

thoroughly efficient, but upon his death his organization may fade away. A corporation is not subject to death, at least not inevitably.

If it were possible to make a comparison between the physical inventory of all corporate property and the mean market value of the securities representing their capital structure, eliminating duplication, the difference, which would be a plus difference, would represent the quantity of their intangible wealth. The grand total would be a capitalization of their expected earning capacity. We cannot usefully explore into this branch of the subject in respect of which so little is known. For the same reason it is idle to attempt comparisons between two different things.

To me the most interesting thing in the data of stock market values and likewise in the corporate revenues as reported to the Bureau of Internal Revenue is the revelation of the magnitude of the wealth that is held and the business that is done through corporations, in which a great many people participate as stockholders. In 1920 about one-third of the national wealth of the United States was in farm property, which is but slightly incorporated.[5] There were then about 6,500,000 farms. The people living otherwise than on farms required about 25,000,000 houses and apartments, the value of which ran toward another third of the national wealth, and that also was in the main privately owned. We do not possess such data for the present time, but perhaps the picture is broadly not very different. Of course we know that there are fewer farms in operation and a much greater occupancy of urban dwellings. A certain proportion of the national wealth is publicly owned. The remainder—comprising mainly our mines, factories, railways, ships, and a good deal of our merchandizing facilities—is now mainly incorporated. I am not here going into the distribution of wealth, for I am naturally cognizant that the ownership of either rural or urban real estate may not lie with the occupant or may be subject to the claim of a mortgagee. However, the broad statement of conditions does suggest a large degree of diffusion of wealth.

[5] There is a present tendency to incorporate agricultural production on a large scale, especially wheat-growing. This may be of powerful political and economic effect.

Now it is clear that the slump in stocks, beginning in 1929, had nothing to do with the quantity of our physical possessions, which probably have continued to increase, although doubtless at a diminished rate in 1930. Also is it improbable that the American people suffered any such shrinkage in their wealth as 75 billion dollars, or 50 or 25. The investor who owned a share of stock worth $100 in 1927 may have seen it quoted at $200 in 1929 and again at $100 in 1930. If he sold at $200 he may have put the proceeds into a share of something else, or he may have done something different. For every buyer at the high prices there must have been a seller; and oppositely at the low prices of 1930.

This is far from leading up to the expression of opinion that the decline in the stock market was an affair of no economic moment. Quite the contrary. It shook our credit structure, forced liquidations and produced sweeping changes in ownership. The trail of commercial insolvencies and bank failures is sufficient evidence of the passage of a hurricane. Let us consider, however, the condition if borrowed money had not entered into the drama. Some of you will immediately answer that stocks would not have risen so high or fallen so low, and assenting to that I save a lot of dissertation. Eliminating the credit constraint, therefore, we are reduced to an association with wealth in only three ways, viz:

1. Insofar as the proceeds of liquidation of securities at high prices, instead of being exchanged for other securities, were diverted to expenditure for consumption goods, thus diminishing savings. We know that this happened to a certain extent, but in comparison with our great aggregate of consumption it may not have been serious.

2. The abstraction by the tax-gatherer, which comes largely to the same thing, but may be more fatal.

3. The possibility that liquidation represented property that itself had become diminished in value or was forecasted as about to become so. This might follow from a change in the habits or the politics of peoples. For example, if the men of the world should decide that no longer were they going to shave, manifestly the capital invested in plants for the manufacture of razors and blades would cease to have value. Political and economic policies leading to strangulation of

consumption would be of more far-reaching effect. Such events might be discounted in the selling of securities, producing a decline in security prices.

The Great War did more than anything else in recent economic history to clarify some ideas and confuse others. Previous to 1914 there was a common belief that warfare would necessarily be narrowed in spread and restricted in time for the reasons that the expense could not long be met, and anyway that the bankers would prevent it going very far. Between 1914 and the end of 1918 we learned the contrary. We learned that the prosecution of warfare was essentially a matter of materials and man-power.

It is conceivable that a great country possessing all necessary resources, e.g. the United States of America if it possessed manganese ore, tin, rubber, nickel, platinum, and perhaps some other commodities, for I am not pretending to make a complete enumeration, might war indefinitely with another great country similarly endowed. The people of each country would be constrained to curtail their scale of living in order to release men and materials for the field, and the end would not come until the destruction of life and the neglect of the upkeep of domestic property and the wearying of one party or the other broke down its morale. By conscription of men and materials finance might not enter into the situation at all; and anyway it would be a domestic affair.

In the Great War the direct destruction of physical wealth occurred only in those countries that were invaded and occupied, especially the north of France and in Poland. Germany did not suffer in that way, but it did indirectly through the wear of its railways and through a robbery of buildings to obtain copper and other necessary material. In respect of other countries any direct losses diminished with remoteness, being less in Great Britain and still less in America. We have seen how rapidly both Germany and France recuperated in a physical way. The physical loss from the war was largely in the diversion of material that otherwise might have been employed for peaceful development, but this was ameliorated by the stimulus of production. More serious was the loss of man-power by mortality and by maiming. The latter produced a burden for support through many years to come.

The financial dislocations occurred through no country being self-supplying and each one having to obtain goods from others and having to enter into debt for them at inflated prices, this indebtedness accruing mainly in favor of the United States, while the debtor countries have aimed to recoup themselves out of Germany. The grievance of the debtor nations against the United States is fundamentally that they got from us one pound of copper and are required to repay to us the equivalent of two pounds insofar as our protective tariff, alcoholic prohibition law, etc., permits them to repay us with goods at all. In our composition of the foreign debts, reduced to present value at rates ranging from 25 to 75 per cent., it is more or less questionable whether we have recognized the principle of deflation or have considered rather the ability to pay. Obviously, in making these remarks I have been speaking figuratively, for Europe had from us many things besides copper. My purpose in drawing attention to this subject is not so much to start an argument as to emphasize the distinction between physics and finance, or between wealth and money, and it seems to me that such distinction should be iterated and reiterated, for misconception prevails in respect of each and does harm in politics.

There is an old adage to the effect that money is the root of all evil. Without any doubt misconception as to money is the root of much economic evil, which may be more serious than the evil of vice to which it is supposed to lead. It has led to the evil of controversies among nations since the war and to internal controversies among classes of people within nations. In almost every civilized nation there is discontent which may be ascribed fundamentally to confusion between wealth and money, and to which largely may be attributed the economic crisis of 1929–31.

How many are the exponents of the classes that do manual labor in the factories and on the farms who cry for the redistribution of wealth through the medium of higher income and inheritance taxes, debenture bounties to farmers, bonuses to veteran soldiers, or otherwise. I fear that they are not thinking so much of the redistribution of wealth as they are of the conversion of wealth into consumption goods, and a different allocation of the latter. If, for example, we decided

to give two billion dollars to the ex-soldiers, we could do it only by borrowing the credit and diverting it from what might otherwise have gone into houses.[6]

If there be any merit in my thesis that wealth grows out of the savings from work, which means production, it is evident that the increment to wealth is not the same every year and may be severely contracted, if not cancelled, in years of depression like 1921 and 1930. The diminishing of work, reflected in unemployment, in such years is ipso facto an evidence of restraint, which conceivably may become substractive. In the support of idle human beings who are no longer creating we cannot feed to them houses and locomotives, but we may allow such things to decay, without replacing them, and that comes to the same thing as if they were fed. This induces me to examine the causes of such a depression as occurred in 1930, our behavior during it, and its effect upon our national economy. This leads naturally to a consideration of the principles of economy distinguished as capitalistic, or more properly individualistic; socialistic; and communistic.

Since the end of the Great War there have been two great economic crises, viz. those of 1920–22 and 1929–1931, which have been of world-wide incidence. In each of them there have been severe declines in commodity prices and high degrees of unemployment in industrial countries. The crisis of 1920–22 was more or less expected and was ascribed to a natural deflationary process. That of 1929–31 was less expected and even after we were well into it there was imperfect appreciation of its nature and scope. The surprise and disappointment produced an unusual psychologic depression that in the course of time became rather hysterical and led many persons into behavior of fright and persuaded many others into making public statements contributing to fright. I offer some illustrations of such kind of talk.

In an address in Wales, Jan. 6, 1931, David Lloyd George,

[6] The translation of national saving into national wealth involves the use of credit. If out of an income of 84 billion dollars we saved 8.4 billion we could not by any possibility lock that up in gold, or money, for the total gold in the United States is less than five billion, while the world's accumulation of gold is only about 11 billion.

the former Prime Minister of Great Britain, declared that unemployment seemed to be creeping over the world because there is too much wealth, too much corn, iron, coal, and other products.

Hon. Albert Johnson, chairman of the Immigration Committee of our House of Representatives, declared that each year the use of labor saving machinery becomes greater, our annual increase of about two million of population, or a large part of it, is added to the ranks of the unemployed, and farming under our standards of living is unprofitable.

A professor in an important university declared that capitalistic society cannot continue to exist, having almost realized itself, with signs of disintegration visible on all sides; that the Russian revolution ushered into the world a social order that is an evolutionary sequence of capitalistic society, dissolving class stratification and exploitation and enabling those who toil at last to enjoy the fruit of their labors.

Beliefs in too much wealth, in the impossibility of further farming, in perpetual unemployment of men, and in the failure of toilers to enjoy the fruit of their toil sound more like the findings of Alice in Wonderland than as the products of clear-thinking. In plain words it is nonsense, all of it.

In general the thoughtless catch-phrases of the day are: Over-production. Under-consumption. Mass-production. Machine-production. Technological unemployment. Three-day weeks. Six-hour days. Wages not to be reduced. Buying power must be preserved. Buyers should not strike. Doles must be given. Ex-soldiers should be pensioned. Work must be made. Bounties must be paid. Build pyramids. Impose tariffs. Avert Russian competition. Pacify the farmers. Government ownership and operation. Democracy ascendant. Crucifixion on the cross of gold. The capitalistic system has wrecked itself, or is about to, and the communistic will supersede it. Uphold the price for wheat, but let us have cheap bread. Those who toil—the proletariat—shall at last receive the fruit of their labor.

This is only a partial enumeration of the hysterical hodge-podge boiling in confused minds. Most of it is in disregard of facts, of analysis, and of common-sense. Most of the prescriptions if applied would make things worse. Some of them

are being applied and this is like trying to cure a body that is sick of arsenic poisoning by giving it more arsenic, under the misconception that it is oxygen. Yet we may recognize that we do need oxygen in our economies and that it is an absence thereof that contributes to depressions even if it does not produce them.

It is not high wages that make prosperity, but it is prosperity that makes high wages. The maintenance of wage scales at which labor cannot find employment does no good to labor or to anyone else. It does not increase buying. On the contrary it is the curtailer of buying. The arbitrary maintenance of wage scales is price-fixing just as much as attempts to maintain commodity prices and one is just as strangling as the other. Municipal employment at fixed wage scales takes from tax-payers what they are unwilling to give privately.

What are the causes of economic depressions? Learned treatises on the subject have been written. What especially are the causes of the depression of 1929–31? This is the subject of immediate interest and concern. There has not yet been time for treatises, but there have been thousands of expressions of opinion in the ephemeral literature. Ninety per cent. of it is silly. Nine per cent. is intelligent but inadequate. The mere declaration of over-production or under-consumption manifestly states merely a symptom without explaining anything. Perhaps one per cent. is scholarly and affords the subject for reflection.

The fact that numerous countries of the civilized world have been concurrently experiencing economic depression indicates a common cause, although it is also to be recognized that a depression beginning in one country for causes peculiar to itself may, and probably will, have repercussions upon other countries, and so we may have the operation of a common factor, or of a special factor, or of both at the same time.

Turning our attention first to the special factors of 1929–31 we think of the following things: The decline in the value of silver, immediately consequential upon a policy of the Indian government, and gravely affecting the economies of the Orient. The collapse of a wild speculation in securities

in the United States. A drought in the United States in 1930. Dislocations resulting from the economic policy of Russia. Everyone is agreed upon the disturbing influence of those events, but after all they are not fundamental, and we seem to have been shaken by something deeper than they. It is in the search for the basic that ideas are so confused. I have tried to classify the elementary opinions:

1. Shortage of gold, with worse to come on that account, not immediately but as time wears on. This is the quantity theory of money in its baldness, and is strongly held by British financiers and economists. Not so strongly by American. This hypothesis has been controversial among economists for three centuries, during which time the negative has strengthened, rather than the affirmative.[7]

2. Maladjustment of gold supplies. This, which is more or less a sub-head, is also a British obsession. Thus, Lord d'Abernon, with this in mind, declared recently that the present depression could be cured in short order by bankers if they would. There are not many who agree with him.[8]

3. The External war debts. The accrual of these mainly to the United States of America and the restrictions imposed upon the importation of goods into the United States are of adverse influence upon international trade. Some great leaders, like Mr. A. H. Wiggin, the scholarly head of the

[7] Apart from the theoretical controversy there is dispute in respect of fact. Some high authorities declare that there has not even been any derangement between commodity production and gold accumulation.

[8] There is a certain difference between total stock of gold and its distribution. The world's total stock of gold over a long period of years has increased at about the same rate as that of the production of all commodities, but beginning with 1928 the holdings of America and France began to rise rapidly while those of the rest of the world began to decline. Inasmuch as stock of gold constitutes a part of any national wealth (although only a small part) fluctuations thereof may theoretically have an effect upon mobile credit, so to speak. The disposition to attribute the recent crisis to shifting of gold has found scant support among the heads of the great banks of London. Reginald McKenna of the Midland laid the blame on "maldistribution of gold," but Sir Harry Goschen of the National Provincial, F. C. Goodenough of Barclays and R. E. Beckett of the Westminster declared the point overstressed, while Beaumont Pease of Lloyds asked what reputable trader in England is unable to obtain credit. The only way America could redistribute its gold would be to spend it or lend it. Absence of confidence may prevent the latter.

Chase Bank, regard this as so adverse that the United States ought further to abate or even to cancel the indebtedness to us for the sake of our own welfare. There is contrary opinion. I do not see in this situation a fundamental cause for the economic depression but it may be an aggravation.

4. Breaking down of the capitalistic, or individualistic, system of economy in the face of the rise of the communistic. Those who express this opinion disregard the evidence that the individualistic system has certainly promoted civilization, while the communistic is still experimental and unproved.

5. Misconception of the nature of wages. This is an attempt to generalize the opinion that the people of depressed countries have lost the idea of working to earn in the futile conviction of working only for a stipend. This is of course the old economic fallacy of a wage fund. In the opposite belief there is plenty of work to be done if the workers are willing. This opinion is expressed by some British publicists, Lord Inchcape for one and by many Americans, who tersely describe our recent situation as a buyers' strike. Willingness on the part of workers is not, however, the only requisite. There is also need for direction of them. The absence of broad direction, which implies planning, may be a reason why the communistic system of Russia is being misconceived as an improvement upon the individualist economy of the rest of the world.[9]

6. Decay of the principle of authority. This means that pure democracy is bound to make a mess of things, out of ignorance and inability to understand, to agree or to act. This was lucidly analyzed and explained by Mallock in his "Limits of Pure Democracy." For the same reasons several countries of Europe have had to resort to dictatorships, with even Germany approaching closely thereto, in order to avert complete disaster.

7. Inevitability. In this opinion depressions are the

[9] My generalization under this head is so broad that I may fail to be understood. I mean that wages are fundamentally a measure of exchange of services. It is upon this that hangs the present controversy over maintenance or reduction of wage scales. It is obscure that while the employer may dispense wages in currency in an envelope it is in the final analysis the consumer who pays them and that the payment is in exchange of one kind of service for another.

natural corrollaries of surges and both are the consequences of miscalculation which in a complex economy cannot be avoided. In other words prosperity entrains its own penalty, for which the thrifty will prepare while the unthrifty will alternate between joyousness and suffering.

I am offering these explanations as I derive them from reading contemporaneous opinions. I may point out, of course, that there is a certain association between the fifth and sixth, and even the seventh, heads; and that the fourth is very much in the nature of an admission of them. Communism, in the Russian experiment, abolishes the wage fund fallacy and decrees working to earn, establishes the principle of authority as never before, and aims to squash the inevitability of industrial cycles by avoiding all miscalculation. Even now there is no unemployment in Russia, but neither is there any in China, where everyone has to toil in order to keep alive.

The discontent with the existing working of things is not confined to the proletariat, but extends to other important classes. It may be described as the complaint of the small men—farmers, tradesmen and merchants—who are being squeezed by the improved efficiency of competitors. This is perhaps the greatest dislocation of what is commonly called mass-production, which may be extended to include mass-distribution. This produces results that inspire paradoxical emotions. The public prays for the cheap wheat of the mechanicalized farm and the cheap distribution of goods by the chain store but objurgates the elimination of labor, whether proletariat or proprietary, that makes them cheap; and endeavors to get even by governmental operation and ownership which do not eliminate any labor and make things cheap only at the expense of tax-payers.

This kind of popular discontent is not assuaged by the production of any evidence of the general distribution of wealth and the enjoyment of the proceeds of efficiency by millions of stockholders, representation of which is a waste of time. It is directed against the intelligence that energizes the corporations, i.e. management, which is popularly generalized as Wall Street. This is the animus of the malcontents of our Senate, who are sometimes described as progressives, but

are moving only toward the form of socialism known as governmental ownership and do not yet understand that the only solution in that direction is the despotic management of the communism of the Soviet.

The individualistic system of economy has a great record of accomplishment, beginning with the steam engine and coming down to electrification, automotive transportation, and the other comforts that are now taken for granted. The communistic system, as exemplified in Russia has not yet proved anything beyond the destruction of academic socialistic thought and the necessity for the reëstablishment of the principle of authority, which has been done in such a way as never before in the history of the world unless under the Roman empire. A main question is whether that authority is being exercised by superior intelligence or inferior. To those who experience an enchantment by the Russian experiment and behold it as the usher of a new era in economy, let me point out that the American people of 125,000,000 souls in 1929 enjoyed a national income of 83.4 billion dollars, and in 1930 in spite of the depression probably about 70 to 75 billion, while 160,000,000 Russians in 1930 had about 18 billion, with the hope of 25 billion in 1931. These figures for Russia are Soviet official. They are computed on the basis of 50c. for the ruble, but externally the ruble is worth only about 20c. Anyway, the communistic economy of Russia, borrowing and hiring the science and engineering of America, has a long way to go. So far as we can see at present the system of communism in Russia has produced only an equality of impecuniosity.[10]

At the same time, however, we may get an idea of the earnestness of the Five-Year Plan and its bearing upon the accumulation of wealth. It is said, unofficially, that about half of the national income is being diverted to the production of new plant, i.e. wealth. This means an enormous contraction of consumption, tightening of belts, but it is so that wealth is created. Consumption may be so much restricted,

[10] The Soviet five-year plan boils down to this: The diversion to the creation of wealth of a large part of a small income, causing the people to live miserably upon the remainder, in the expectation that eventually income will be increased and the scale of living will consequently be improved.

however, as to impair efficiency in production. There was a man who taught his horse to eat wood shavings, but unfortunately the horse died.

The thesis of my lecture, as by this time you are well aware, is that wealth grows out of work and thrift. Another expression of this is income and savings. This is so obvious that I feel trite in saying it, but I find a good reason in the observation that millions of our fellow citizens believe otherwise, and so do millions abroad.

We are familiar with the motions for reduced working time in order to equalize the opportunity to work. We are told that we have so multiplied our man-power by machinery that we produce too much and throw men out of employment. The arguments that are made are so plausible that they deceive many who are endowed with commonsense, although they contravene common sense. They are equivalent to saying that the more goods we possess the worse it is for everyone.

There can be over-production of some things, of foodstuffs for example, for a population that enjoys enough thereof to be reasonably fat cannot eat any more, anyway ought not to try. On the other hand, there is no limit to the comforts and luxuries that a people may want and can have by working for them. Throughout our economic history the natural increase in the number of workers, plus all of the machinery that we have been able to contrive, has been absorbed in building railways, highways, bridges and skyscrapers; in providing us with sewing machines, automobiles and electrification in a myriad of ways. We should have been backward in our civilization if we had not had the men, plus machinery, in order to do such things. How else would the Panama Canal have been built; or would New York have had its water supply and Chicago its drainage? There is no reason to suppose that future conditions are going to be otherwise.

All of the present talk of mass production, over-mechanicalization and technological unemployment is one of the most vicious of the fallacious conceptions that afflict us. Pursuance of such conceptions leads not to wealth but to poverty. It is doubtless true that at times there are dislocations that

develop temporary unemployment. Such occurrences are one of the penalties of prosperity. The thrifty are expected to set aside a part of their income in prosperous times to meet just such contingencies. Of course there are many who do not for the simple reason that they are unthrifty.

What is called mass-production or machine-production means economical production, i.e. production with the minimum of labor. Instead of such a movement being contributory to crisis it is crisis itself that intensifies or produces the movement. A management engaged in the production of a commodity and confronted by a falling price and a shrinking margin may require its men to reduce the labor component by accepting a lower wage, or it may inspire its engineers to improve methods so as to dispense with some men or so as to lead to more work and more production per man. If the operation is to survive, one of those things must be done in order to preserve work for anybody. If the men are unwilling to accept such alternatives unemployment is bound to increase.

In considering the existing unemployment in the United States it is important to inquire how much of it is ascribable to the wilfulness of workers themselves; how many of them are like the man who sawed off the limb of the tree on which he was sitting. How have the building mechanics checked building by making it too costly? How have the miners and handlers of anthracite coal curtailed its use by causing the price to consumers to become prohibitive? How is railway transportation being diverted to truck, boat and pipe-line? How has domestic help become nearly extinct? How were the theaters constrained to dispense with their musicians? How has shoe manufacturing been driven from Lynn, Haverhill and Brockton to country towns? I need not multiply these questions any more. The answer is to be found in the indices of the Federal Reserve Bank of New York, taking the month of November, 1930, and comparing with 100 for 1913: Composite index of wages, 219; general price level, 161; cost of living 161; and, according to the Annalist, commodities, 115.

I am not indicting organized labor, or its leaders, which comprises only about 3.5 million of our workers out of our

present total of about 40 million non-agricultural, although it is the most voluble. Unorganized labor has the same misconception as organized that wages are derived as dollars from some mythical reservoir instead of being a dollar measure of what is earned. On the eve of the depression in 1929 the building mechanics in my home territory raised their terms 10 per cent. and in 1930 they contemplated a further increase with the explanation that if they were able to get work for only two days a week they would have to receive more per day. At the same time our dealers in anthracite raised their price a dollar a ton. This is obviously commercial thought upside down.

So it is that in the United States we have an appearance of over-production, under-consumption and unemployment at a time when we are nationally short of housing, when many homes are awaiting electrification, when many communities have no supply of running water, and when we have many acres of idle land, some of it in proximity to great cities, that is awaiting clearing, and many more acres, more remote, that ought to be reforested. We have the labor, the tools and the credit with which to do such things, but under existing conditions we can not afford to do them. We have been having a buyers' strike.

In the cities I have read reports of hunger and I have seen bread lines. I feel a special sympathy for the people in a city, standing on pavements and confined by brick walls, living under conditions of helplessness. It seems to me unfortunate that there has been so extensive a migration to the towns and congestion in them. It would be better if when work becomes slack in factories in the cities people were able to return to the country where they could at least have shelter, fuel and food.[11] But even in my countryside I hear of families suffering from cold and hunger although we have plenty of wood and plenty of idle land that is capable of furnishing food to those who will grow it. I can understand the reports of famine in Arkansas where there was drought,

[11] The manufacturing industries of New England were born in small towns, with open country around them. Concentration in large cities came later. Recent tendencies toward dispersal have been salutary. When wheels have to run slow in the mills men may then work on the land.

an adversity of nature, but reports of farmers in Dakota and Manitoba being on the verge of starvation are not convincing.

Surveying the situation in Europe we discern similar conditions. Great Britain is short of housing, is in need of electrification, and ought to scrap and rebuild much of its manufacturing plant. Germany is even more short of housing. Both countries have idle men and plenty of material. Chancellor Bruening, at least, is endeavoring to stimulate domestic work for domestic needs.[12]

Please do not think me to be regarding the problem as being quite so simple as I have just been expressing it. Political acts play enormous parts. Great Britain, for example, debased its silver coinage, liquidated the silver release, and later by leading India toward the gold standard precipitated a decline in silver, depreciated the silver wealth of India, which is estimated at seven billion ounces and upset the economy of China. As a consequence the Orient was able to buy less from Great Britain and some of her chimneys ceased to smoke and collieries had diminished markets and colliers became idle. In every country the cost of government has risen, which means more officials to be supported by taxation. I am not shutting my eyes to any of these evils, but I am arguing that they are not inherent to capitalistic economy and that neither they nor what is called overproduction are evidences of break-down.

It is far from my mind that our affairs are preordained and that there is no requirement of thought and leadership. I have previously suggested that we may well consider the administration of oxygen if not arsenic.

With those who become idle by their own wilfulness I have no sympathy. Let them starve until they cease to be wilful. We have certain classes of labor who think they have a stranglehold upon their industries which are so obstinate

[12] In respect of Great Britain and Germany the index numbers for commodity prices, cost of living, and wages for labor are similar in their unbalance to those of the United States. In this there is in common a fundamental factor producing economic disturbance. It is at least significant, said Dr. T. E. Gregory, Cassel professor of banking at the University of London, that the rigidity of wages is a striking feature in the economic situation in Great Britain.

that they will never surrender and seem to me to be predestined to become perpetually idle or semi-idle. Them we must accept as a handicap in our economy. I do not suppose that such obstinates exceed 2 per cent. of our non-agricultural workers and they will gradually die off.[13]

We may feel a sympathy, however, and give consideration to those who have been led to the making of automobiles, for example, and whom we have been obliged to lay off for the reason that owing to industrial miscalculation there were too many automobiles made with the exigency of a halt until stocks could be absorbed. It is insufficient to say to such workers that they ought to have been thrifty and saving in the good times. Many of them will have been unthrifty. In respect to their personnel the leaders of industry are feeling more social responsibility and are endeavoring to take care of their workers by part-time arrangements.

But as to the workers who are permanently released by labor-saving economies? Eventually they will be absorbed into new occupations, as also the three quarters of a million of new workers who every year are added to our number. The automobile industry, which in one way or another is supposed to engage about 10 per cent. of all of our workers non-agricultural, was the great absorber during the last decade. During the next that will no longer be so, but by no means is our culture culminating with the automobile. Something new is going to come, leading to a higher scale of living. It may be through the solving of the secrets of chemistry and physics that our scientists are exploring in their laboratories. A retrospect of the last 10 years makes us think that we are but on the threshold of a new era of applied science and that all available man-power will be required.[14]

In such interims, however, we should have means of utilizing all man-power that is waiting, putting it to useful

[13] The deflation of labor in the United States has already proceeded further than has been published but it has been mainly among the ranks of those who produce raw materials and the primary fabrications rather than among those who transport and distribute them. The latter throttle the outlets for cheap materials. There results an inverted spiral instead of one that rises and expands.

[14] Let us imagine, for example, the commercialization of means for cooling our houses in summer just as we heat them in winter.

work, not building useless pyramids; but the man-power itself should be coöperative and not assumptive of the position that the world owes it a living. This seems to me to be a broad generalization of our great problem. It means a reëstablishment of the principle of the authority of intelligence, the loss of which has been the great misfortune of the world since the economic chaos of the ending of the Great War.

I find Mr. John Maynard Keynes, one of the most brilliant of British economists, exhibiting a similar foresight in a recent article in one of the British magazines, wherein he remarked:

"We are suffering, not from the rheumatics of old age, but from the growing pains of over-rapid changes, from the painfulness of readjustment between one period and another. The prevailing world depression, the enormous anomaly of unemployment in a world full of wants, the disastrous mistakes we have made, blind us to what is going on under the surface—to the true interpretation of the trend of things."

We find ourselves now confronted by the present paradox of an enormous unemployment in the principal countries of the civilized world which are full of wants and possess a bounty of foodstuffs for the support of their people and of materials for the creation of wealth. I may speak alliteratively of the paradox of poverty amid plenty. I have tried in my analysis to probe for the reasons for so strange a situation. Even if I have done no more than be suggestive, it does not follow that correctives are easy of application. On the contrary the correctives, which appear to be of a psychologic and political nature, may be extremely difficult to bring about. What we need more than anything else is a restoration of the principle of authority, by which I mean the leadership of intelligence. I do not think that the people of either America, Great Britain or Germany will want to acquire such leadership in the form of the severity of communism as developed in Moscow.

I have so frequently referred to the Russian experiment that my audience may begin to think that it is on my mind and that perhaps I am unconsciously sympathetic with it.

It is on my mind in the sense that it seems to me to be giving us an object lesson irrespective of whether it prove successful or unsuccessful. I am doubtful whether it be communism so much as conscription. Its economic essence is the creation of wealth out of work and inasmuch as present productivity is low the scale of living is pared in order to afford a surplus. Internal quarrels over the distribution of wealth have been abolished by nationalizing all property, and over the division of income by equalizing the scale of living, except in respect of two favored classes—the army and the engineers. The services of the latter are so vital that a large number of Americans and some Germans have been hired at capitalistic rates. Without their services the whole experiment would undoubtedly fail and it is to enjoy them that the Russian people are deprived of consumption goods that are needed for themselves. In this there is a good deal that is pathetic. There is also an economic contradiction in the practical recognition that the laborer is worthy of his hire.

The answer to the Soviet experiment will not be obtained until many years after the five-year plan has been completed. It will be determined by the finding whether the Russian people are sufficiently industrially minded to conduct things themselves, whether the absence of personal incentive is ipso facto destructive, whether the economy of 160,000,000 people can be competently directed by a bureaucracy. In respect of the first of these conditions we may properly say that we do not know. As to the second the economic history of the world indicates the affirmative. As to the third we are sure that we should be aghast at the thought of turning over the management of all American affairs to our bureaucracies, federal and state, even if they were freed from interferences by Congress and legislatures and the irresponsibility of politics and democracy. Our experience in railway operation during the war and subsequently is still fresh in our minds.

What the Russian experiment does tell us, however, is that the wealth and welfare of a people is spelled by farms, mines, houses, railways and factories; and that such things are obtainable only by work and thrift. Our forefathers in Massachusetts also appreciated that though they did not express themselves in economic terms, nor were they economic-

ally introspective. An export trade is inherently necessary only to acquire what a country does not possess. The present need of Russia is for knowledge, experience and machinery, wherefore it has to export its wheat that it might otherwise keep at home.

This is so evident that the statement of it is something like the declaration that every day the sun rises and sets. Nevertheless we have to recognize that the operation of individualistic economy is frequently contrary to principle. The sun rises and sets every day but often it is obscured by clouds. Idleness occurs and the creation of wealth ceases owing to miscalculation, absence of general planning, class-quarrels over division of income and artificial restrictions in the interest of one class or another. This is the explanation of the paradox of poverty amid plenty. So long as a people have unsatisfied needs such a condition ought not to exist. I think we have been conscious of that for half a century and have been trying to apply correctives, many of which have been wrong, many of which have aggravated the evils that it has been sought to correct. It does not follow from this that our minds have become exhausted, and our system bankrupt, or that it is necessary to destroy it all so as to resume living in an equality of poverty. Whether we like it or not, science teaches us that all men are not created equal and the great natural law of the survival of the fittest is bound to operate inexorably. The most that we can do is to give all men an equal chance.

A PHOTO-ELECTRIC INTEGRAPH.

BY

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ABSTRACT.

A machine for the purpose of facilitating mathematical solution of problems requiring the evaluation of an integral in which the integrand involves a variable parameter is described in this article. It involves the use of an optical system in which the transmission of light is limited in a definite manner by apertures having the shape of the area under curves representing mathematical functions. The accuracy of the machine itself is from 2 to 5 per cent. Examples of the use of the device in the solution of the superposition theorem integral and a form of integral equation are given. Its application to other problems including the Fourier transform, correlation analysis, and periodogram analysis is discussed, and its limitations are considered.

INTRODUCTION.

Progress in engineering and other scientific fields is determined in a large measure by the development of mathematical methods as applied to them. As analytical methods of formulation are extended, new methods of solution are desirable, and machine processes are destined to play an important part. The Photo-Electric Integraph described in this paper is one portion of a general scheme of development of computing devices in progress at present at the Massachusetts Institute of Technology. It extends the range of practical solution of mathematical problems through its usefulness in the evaluation of integrals having a variable parameter within the integrand, such as those found in the Fourier transform, the superposition (Duhamel's) theorem, and certain forms of integral equations. It evaluates an integral of the following general form:

$$y(t) = \int_a^{t \text{ or } b} z(t \pm \lambda) g(\lambda) d\lambda, \qquad (1)$$

where $z(\lambda)$ and $g(\lambda)$ are known functions.

The foregoing mathematical relationships appear in many fields of investigation, and the application of the machine is extensive. In particular, it is useful in the study of transients in electric circuits, for in this case, by means of the Fourier transform and the superposition theorem, a knowledge of the impedance of a circuit as a function of frequency is the only requisite for the determination of the complete transient response of a network to any applied voltage.[1] The Fourier transform gives a direct relationship between the impedance function and the transient resulting from a suddenly applied voltage, so that with either given, the other may be found. Because of its reciprocal nature the form of the integral to be evaluated is the same in either case. The superposition theorem makes possible the determination of the alternating-current transient of a network due to an applied voltage of any form when the current transient resulting from the sudden application of a unit voltage, generally called the indicial admittance, is known. A simple formulation of the problem of a circuit having a variable parameter, such as the thermionic tube, rectifier, or rotating machine can be made by means of an integral equation. Other useful applications of the machine, to mention but a few, are in periodogram analysis [2] of river-flow, weather behavior and other irregular phenomena, in the evaluation of correlation coefficients, and in some problems of atomic physics.

The Fourier transform, the superposition theorem, and certain types of integral equations all contain similar integrals, and can be treated with the same machine. One of the simplest forms of the superposition theorem is

$$i(t) = \frac{d}{dt}\int_0^t A(t-\lambda)e(\lambda)d\lambda. \qquad (2)$$

Several other forms can be derived from this and in an example given below, the following one will be used

$$i(t) = e(t)A(0) + \int_0^t A'(t-\lambda)e(\lambda)d\lambda. \qquad (3)$$

[1] Bush, V., "Operational Circuit Analysis." John Wiley and Sons, 1929.

[2] Wiener, N., "Generalized Harmonic Analysis," *Acta Mathematica*, **55**, 118–258, 1930.

A form of the Fourier transform which may be used to represent odd functions is

$$f(\omega) = \sqrt{\frac{2}{\pi}} \int_0^\alpha g(\lambda) \sin \omega\lambda d\lambda, \tag{4}$$

$$g(\lambda) = \sqrt{\frac{2}{\pi}} \int_0^\alpha f(\omega) \sin \omega\lambda d\omega, \tag{5}$$

and the form for the representation of even functions is similar except that the cosine enters in place of the sine. The integral of expression (4) can be reduced to an integral similar to that in the superposition theorem by the following transformation, as shown by Wiener, and suggested by Romanujan.[3]

$$f(\omega) = \sqrt{\frac{2}{\pi}} \int_0^\alpha g(\lambda) \sin \omega\lambda d\lambda.$$

Let

$$\lambda = e^u,$$
$$d\lambda = e^u du.$$

Then

$$f(\omega) = \sqrt{\frac{2}{\pi}} \int_{-\alpha}^\alpha g(e^u) \sin e^{(\log \omega + u)} e^u du,$$

which is in the form of

$$f(\omega) = \sqrt{\frac{2}{\pi}} \int_{-\alpha}^\alpha G(u) \phi(\log \omega + u) du, \tag{6}$$

where

$$G(u) = e^u g(e^u); \qquad \phi(\log \omega + u) = \sin e^{(\log \omega + u)},$$

and can be treated by the machine. Finally, one form of the Volterra integral equation is

$$f(t) = f_0(t) - \frac{d}{dt} \int_0^t A(t - \lambda) g(\lambda) f(\lambda) d\lambda, \tag{7}$$

and a more general type of integral equation is

$$f(t) = f_0(t) - \frac{d}{dt} \int_0^t A(t - \lambda) \psi[f(\lambda)] d\lambda. \tag{8}$$

[3] Hardy and Littlewood, *Acta Mathematica*, **41**, 158, 1918.

In equations (7) and (8), $f(t)$, the unknown function, appears under the integral sign, and a direct solution is difficult to obtain. By a method of approximations making use of a succession of assumed functions, each a modified improvement over the preceding one, a solution may be had in many cases. In this problem, then, as well as the previous ones, the solution may be said to depend upon the evaluation of an integral of the common form,

$$y(t) = \int_a^{t \text{ or } b} z(t \pm \lambda) g(\lambda) d\lambda, \qquad (1)$$

where $y(t)$ is the only unknown function.

Integrating devices have been developed which will evaluate the integral of a functional product, even when the functions of the integrand are of complicated analytical, or graphical form, and the Product Integraph [4, 5] is a notable example. This machine is of the continuous recording type, giving the integral graphically as a continuous function of the upper limit, and the value of the integral between definite limits is the end result of the integration process. If a parameter is included in the integrand, the result is given for one value of the parameter only. Expression (1) requires such an integral as a continuous function of the variable parameter, hence an infinite number of the above evaluations would be necessary to obtain this result. An entirely different type of machine is needed therefore for evaluating (1), namely a device in which the integral between assigned limits of the variable of integration is indicated continuously as a function of the variable parameter. In some cases, the parameter may appear also as the upper limit of the variable of integration.

A suggestion of Dr. Norbert Wiener that an integrating device of the necessary nature for the evaluation of the variable-parameter integral could be constructed using radiation passing through apertures whose shape represents the functions to be multiplied and integrated, has led to the construction of the present machine. This was undertaken as a thesis for the doctorate under the direction of Dr. V. Bush.

[4] Bush, V., Gage, F. D., and Stewart, H. R., "A Continuous Integraph," JOUR. FRANK. INST., Jan. 1927, pp. 63–84.

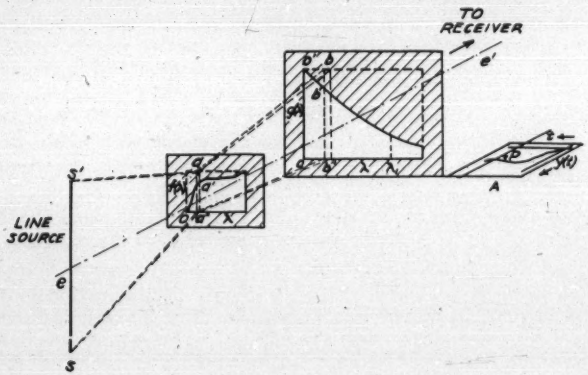
[5] Bush, V. and Hazen, H. L., "Integraph Solutions of Differential Equations," JOUR. FRANK. INST., Nov. 1927, pp. 575–615.

Previous work was done on the problem by Gould.[6] Infra-red radiation was used in his device, and the difficulties encountered in the control of extraneous radiation and the measurement of the desired quantity were great. Since then, the development of photo-electric cells and improvements in their reliability and constancy have made their use practical and satisfactory for measurement of radiation in the visible spectrum as is done in the present machine, with an attendant decrease of difficulties.

PRINCIPLE OF THE MACHINE.

Essentially the device is based upon an optical system of the type shown in Fig. 1. In this figure, SS' represents a line

FIG. 1.



Perspective diagram of light source, function masks, and result platen.

source of light having uniform brightness along its length. Light from the source falls on the face of a cardboard mask through which an aperture is cut in the shape of the area under any function $f(\lambda)$ which can be plotted. A similar function mask for $g(\lambda)$ plotted with twice the linear distance for the same range of λ, i.e. double scale, is located on the same

[6] Gould, K. E., "A New Machine for Integrating a Functional Product," M. I. T., *Jour. Math. and Physics*, 3, 309, 1928.

optical axis, ee' so that the distances from the $f(\lambda)$ mask to the light source and to the $g(\lambda)$ mask are equal. This distance is made sufficiently great so that the variation of intensity of the radiation incident upon the face of the $f(\lambda)$ mask from any point along SS' is less than one per cent. Then it follows that the distribution of intensity of light over the face of the $g(\lambda)$ mask due to light passing through the $f(\lambda)$ mask is substantially uniform along any narrow vertical element of area such as bb'', and is proportional to the portion aa' of the elementary area aa'' included under the function $f(\lambda)$, i.e. to the ordinate of $f(\lambda)$. The amount of radiation which passes through the vertical area on the $g(\lambda)$ mask is therefore proportional to the product $f(\lambda)g(\lambda)$, and the total amount of light which passes through the $g(\lambda)$ mask in the range $\lambda = 0$ to $\lambda = \lambda_1$ is proportional to

$$\int_0^{\lambda_1} f(\lambda)g(\lambda)d\lambda. \tag{9}$$

When the variable parameter is introduced in the form

$$\int_0 f(\lambda)g(t - \lambda)d\lambda \tag{10}$$

the integral can be treated in the following manner. The $g(\lambda)$ mask is plotted as usual and reversed, or revolved about oo'. If it is then moved horizontally a distance t into the field illuminated through the $f(\lambda)$ mask, the ordinates exposed to the light from $f(\lambda)$ are those corresponding to $g(t - \lambda)$ and the total light which passes through is proportional to integral (10) as the distance t is varied. For the evaluation of

$$\int_0^b f(\lambda)g(t + \lambda)d\lambda \tag{11}$$

the principle is similar except that the mask is not reversed, and the movement corresponding to the parameter t is in the opposite direction. In the treatment of an integral of the form

$$\int_a^b f(\lambda)g(t \pm \lambda)d\lambda, \tag{12}$$

where a and b are constants, the range of λ over which light passes through the $g(\lambda)$ mask is fixed, and the mask is plotted

to extend sufficiently to each side of this range to permit a horizontal shift corresponding to the range of t.

A graphical record of the value of the integral as a function of the variable parameter is made by recording the amount of light which reaches the receiver as a function of the horizontal position of the $g(\lambda)$ mask. The record is made on a platen, shown at A in Fig. 1, which moves with the $g(\lambda)$ mask as t is varied. The light converges from the $g(\lambda)$ mask through a lens system into one of two photo-electric cells. Light from the same source SS' is led through a second optical system into the other photo-electric cell. A shutter with linear calibration is located in this second or auxiliary-optical system to provide means for keeping the amount of light to the two photo-electric cells equal, a condition which is indicated by a galvanometer. If the shutter is so adjusted for each position of the movable function mask $g(\lambda)$ that the galvanometer shows balance, its opening is then proportional to the value of the integral for the corresponding value of the parameter t. The shutter is connected mechanically to the pencil P which records the result curve proportional to the integral on the platen A, Fig. 1.

DESCRIPTION OF THE MACHINE.

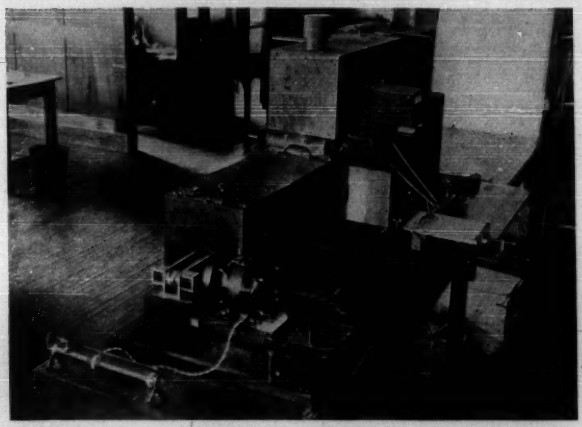
The manner by which the principles outlined above have been incorporated in the machine involves some deviation from that indicated by the schematic diagram of Fig. 1 due to practical considerations. A view of the machine assembled for operation is given in Fig. 2. The optical systems are enclosed by removable panels to exclude extraneous light, and Fig. 3 shows the machine with several of the panels removed.

The difficulty of obtaining a line source of light of sufficient length and uniform brightness has led to the use of a virtual image as a source instead. This is obtained as the image of a light source given by a mirror oscillating through a small angle with uniform angular velocity. Only on the average can such an image be considered a line source of uniform intensity, and it is necessary therefore to adapt the measuring part of the machine to this departure from the basic principle, in a manner which will be described. The light source, an incandescent lamp of 200 watts rating having the equivalent

of a short line filament, is located in a metal cylinder at *A*, Fig. 3. The radiation from this is directed toward the face of a mirror *B* which is mounted on a horizontal axis in the oscillating device shown in Fig. 4.

The angular oscillations of the mirror are obtained by the use of a crank mechanism, or four-bar linkage. A crank driven by the motor is coupled by a long connecting rod to a second crank which has a throw of 101.5 per cent. of that of the

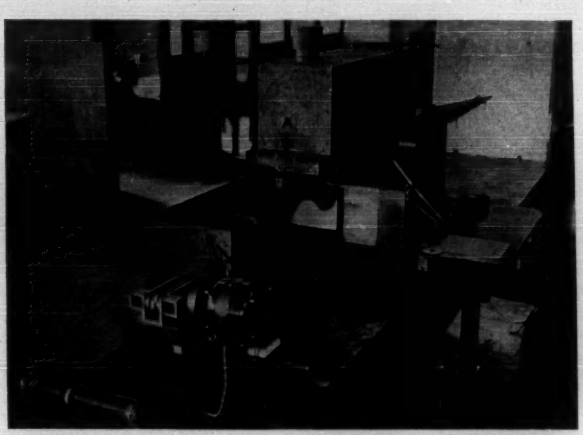
FIG. 2.



General view of the photo-electric integraph.

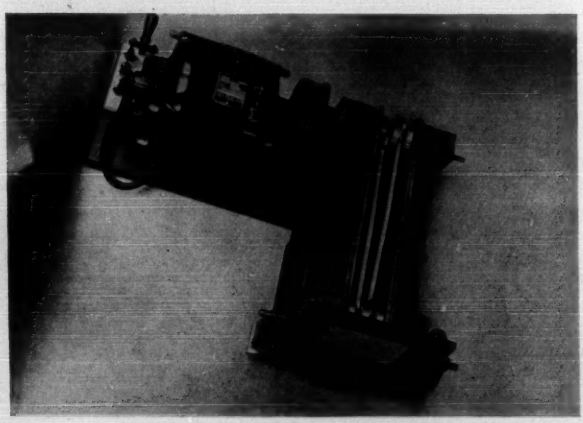
driving crank, the distance between centers of the two crank shafts being equal to the length of the connecting rod. The driven crank oscillates through approximately 160 degrees, while the driving crank rotates continuously in one direction. Two complete crank mechanisms set in opposition are used for balancing to prevent vibration. During the greater part of its rotation, the motion of the driven crank is substantially uniform, and only this part can be utilized. The shaft of the driven crank is geared by a ten-to-one reduction to the mirror shaft, and the remainder of the dimensions of the optical

FIG. 3.



View of the instrument with panels removed giving access to the optical systems.

FIG. 4.

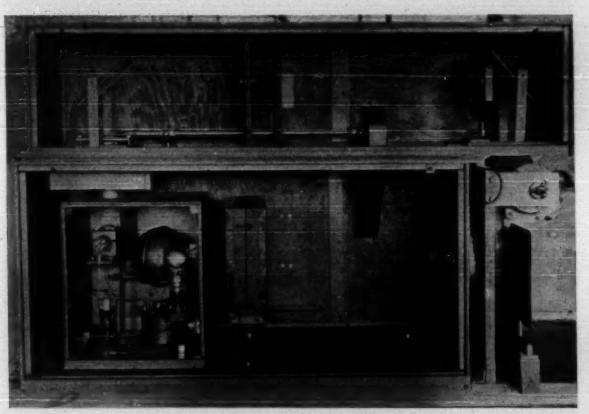


The mirror oscillating mechanism.

systems are such that light from the virtual image passes through the $g(\lambda)$ mask only during that portion of the cycle in which the angular velocity of the mirror is nearly constant.

The $f(\lambda)$ mask is held to the face of the mirror B in grooves, while the $g(\lambda)$ mask appears in Fig. 3 attached to a carriage upon which the result platen moves just below the light source. The light, having been reflected from the oscillating mirror through the two masks, is converged by a lens system into an integrating sphere, shown in the box containing the photo-electric cells in Fig. 5.

FIG. 5.



The auxiliary optical system, and photo-electric cell compartment.

The purpose in using the integrating sphere, a suggestion of Professor A. C. Hardy, is to eliminate the directional effect of the photo-electric cell which receives the main beam of light. It is well known that the direction from which light strikes a photo-electric cell has considerable effect on its response. The main photo-electric cell is therefore mounted near a window in the side of the sphere through which it receives the light to be measured. This light has been diffused by the

magnesium-oxide surface inside the sphere and averaged or integrated with respect to direction. The response of the photo-electric cell to light passing through any part of the illuminated field of the $g(\lambda)$ mask is rendered constant by the sphere to well within the accuracy desired in the result.

The path of the auxiliary light beam to the second photo-electric cell is upward from the light source at the right of Fig. 5 to a mirror from which the light is reflected horizontally. It is then converged by a lens, and sent through a sheet of plane glass to a ground-glass plate mounted in the central partition of the upper compartment. From this it passes to the face of a second mirror at the left of the figure where it is reflected downward through the shutter. A second lens finally directs the auxiliary light beam into the photo-electric cell located in the shielded box below.

The plane glass and the ground-glass plates are employed for the purpose of varying the maximum amount of light which can pass through the auxiliary-optical system, and thus of providing a method of adjusting the scale of the result curve drawn on the instrument. On the face of the ground-glass plate, diaphragms with circular apertures of various sizes may be placed. Selection of one of these gives a rough adjustment on the amount of maximum light. The plane-glass plate furnishes a vernier adjustment covering the intervals between the diaphragms. This plate may be rotated about a vertical axis to change its angle with the optical system. The amount of light reflected at its surfaces is dependent upon the angle, and by moving it through its complete range of seventy degrees, the light through the optical system may be varied ten per cent.

The calibration, linearity, and accuracy of the machine depend upon the construction of the shutter in the auxiliary-optical system, which is similar to the one used by Jones,[7] and by Hardy.[8] It is actuated by a worm and gear drive from a lead screw which is turned by a crank and runs across the top of the result platen shown in Figs. 2 and 3. A pencil rider is

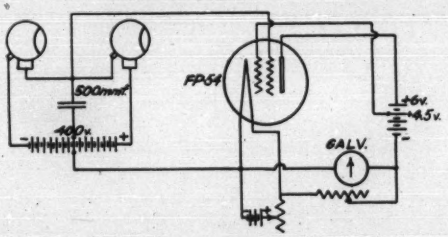
[7] Jones, L. A., "An Instrument (Densitometer) for the Measurement of High Photographic Densities," *J. O. S. A. and R. S. I.*, **7**, 231, 1923.

[8] Hardy, A. C., "A Recording Photo-electric Color Analyser," *J. O. S. A. and R. S. I.*, **18**, 98, 1929.

driven by the lead screw so that ordinates on the result plot are proportional to the opening of the shutter and therefore to the amount of light in the auxiliary photo-electric cell, which in turn is made equal, by comparison, to the light in the main photo-electric cell, and thus to the integral of the product of the functions in the machine. Motion corresponding to the abscissæ i.e., variable parameter, is given to the result platen and $g(\lambda)$ mask by a second crank and lead screw.

The electrical circuit by which the condition of balance is shown between the two photo-electric cells is that of Fig. 6. Use of this was suggested by Professor Hardy, and it has important advantages. The photo-electric cells, of the high

FIG. 6.

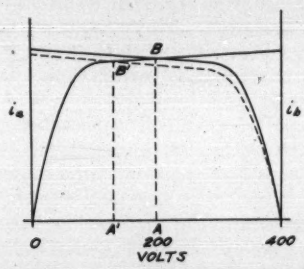


The electrical circuit of the photo-electric integraph.

vacuum type, are arranged in series across a battery of 400 volts. The common point of the photo-electric cells and the mid-point of the battery are connected, respectively, to the grid and the filament of a thermionic tube. If the quantities of light which pass into the two photo-electric cells are equal, and the cells are identical, the potential difference across the thermionic tube is zero. However, it is necessary to modify conditions somewhat in order to utilize the thermionic tube for indicating this condition of balance, for the normal operating potential of the grid is negative. If then, the mid-point connection to the battery is displaced by the amount of this negative bias, equal quantities of light in the photo-electric cells impose the normal bias on the tube, and rated current flows in the plate circuit. A rugged galvanometer is

used to measure the plate current, and a variable resistance and a battery are connected to balance out the normal current and bring the galvanometer to its zero point. A small unbalance in light between the two photo-electric cells is indicated on the galvanometer, and due to the saturation characteristics of the high-vacuum photo-electric cell, the sensitivity of the method is great. It depends principally upon the extent to which the cells do saturate with voltage, as can be seen from a consideration of Fig. 7. The characteristics of the two photo-electric cells when equal quantities of light fall in them are represented by the solid lines. The currents in the two cells are equal, and the point B which satisfies this condition indicates the equal division of voltage

FIG. 7.



Curves showing the relations of current and voltage in the photo-electric cell circuit.

across them, and also the potential of the common point of the cells. For some other slightly smaller quantity of light in one of the cells the characteristic will become as shown by the dotted line, the division of voltage will be unequal, the potential of the common point will be that of the point B', and the voltage AA' will be impressed on the thermionic tube. The magnitude of the voltage unbalance caused by an increment of light intensity is thus seen to vary with the slope of the upper part of the curve and a flat characteristic is desirable for high sensitivity. Commercial cells of the General Electric P.J.-14 type are used. A further advantage of the circuit is that the sensitivity is nearly independent of the amount of light in the cells when it is approximately

balanced, for the effect of changing the light intensities corresponds substantially to altering the current scale of Fig. 7. Also, fluctuations in the light source do not affect the balance for the same reason.

In order to realize the advantages of the method, it is necessary to use a device for indicating the balance condition which does not disturb the proper operation of the photo-electric cell circuit. The device should have a high resistance in comparison to that corresponding to the slope of the upper part of the saturation characteristics of the cells, and it should have a low capacitance.

The lag in indication, which is substantially the time required for the circuit to reach equilibrium after a change in the amount of light entering one cell, is proportional to this capacitance, and it may be of sufficient magnitude to make the device slow in operation. However, a certain amount of capacitance is necessary in order that the average balance conditions over the oscillating mirror cycle shall be indicated by the galvanometer, and the equivalent use of a moving light source justified. The value of capacitance used, which is sufficiently large to introduce the averaging character of the measuring circuit, and at the same time sufficiently small to maintain the lag in indication at a minimum, is approximately 500 micromicrofarads. The thermionic tube,[9] kindly furnished by the General Electric Company, possesses the important feature of a grid-filament resistance of the order of 10^{16} ohms. In addition, it is necessary to shield the circuit from electrostatic disturbances, and to use guard rings to reduce the effect of leakage resistance over the surface of the photo-electric cells.

METHOD OF OPERATION AND APPLICATION.

With the masks in place and the diaphragms set for proper light through the auxiliary system, the result curve is drawn by manual operation of the two cranks. With the left hand the operator turns one crank thereby moving the $g(\lambda)$ mask through the range of the variable parameter. With the right hand he turns the second crank in such a manner that the

[9] Metcalf, G. F., and Thompson, B. J., "A Low Grid-Current Vacuum Tube," *Phys. Review*, **36**, 1489, November 1, 1930.

light through the auxiliary system is kept equal to that through the main system as indicated on the galvanometer. The time necessary for drawing one curve depends upon the accuracy desired, but in no case should it amount to more than five minutes.

The scale of the result curve may be determined after the curve is drawn, or it may be made definite beforehand. In either case the method used is to evaluate the integral

$$F(t) = k_1 k_2 \int_0^t d\lambda = k_1 k_2 t. \qquad (13)$$

The masks corresponding to k_1 and k_2 are rectangular openings of a definite height. When these are placed in the machine the curve drawn is a straight line through the origin with the slope $k_1 k_2$. If this curve is drawn with the auxiliary system having the same setting as that used on an unknown integral, the scale of the result curve is determined according to the slope of the straight line on the result sheet. If, however, it is desired to predetermine the scale of the result curve, the rectangular masks are used and the diaphragms in the auxiliary system so adjusted that the straight line passes through a chosen point on the result curve paper before proceeding with the evaluation.

The masks used are cut from black cardboard with a sharp knife. The curves may first be drawn on graph paper and subsequently transferred to the cardboard by any desired means. The masks are of two sizes with a ratio two-to-one, the dimensions of the larger being 6 by 8 inches, and those of the smaller 3 by 4 inches. They are attached to the mirror frame and the wooden frame by means of grooved ways into which they are slid.

It is to be noted that negative values cannot be treated by the machine directly. Thus, where the functions to be operated upon contain both positive and negative values, it is necessary to bring them above a zero axis by the addition of constants. The result curve is then corrected for the constants by subtracting other curves dependent upon the particular problem. For instance, should it be desired to evaluate,

$$\int_0^t f(\lambda) g(t - \lambda) d\lambda, \qquad (10)$$

where both $f(\lambda)$ and $g(\lambda)$ contain positive and negative values, the constants k_1 and k_2 are added so that the resulting curves fall on the positive side of the axis. The integral then becomes

$$\int_0^t [f(\lambda) + k_1][g(t - \lambda) + k_2]d\lambda, \tag{14}$$

which reduces to

$$\int_0^t f(\lambda)g(t - \lambda)d\lambda + k_1\int_0^t [g(t - \lambda) + k_2]d\lambda + k_2\int_0^t [f(\lambda) + k_1]d\lambda - k_1k_2t \tag{15}$$

Thus from the result curve given by the machine it is necessary to subtract

$$k_1\int_0^t [g(t - \lambda) + k_2]d\lambda, \qquad k_2\int_0^t [f(\lambda) + k_1]d\lambda$$

and add k_1k_2t to obtain the result of expression (10)

An alternate and sometimes more satisfactory method which uses the curves plotted on their normal axes is also available. The result curve is obtained by the algebraic addition of four integrals, the sum of the two given by multiplication of the portions of the curves of unlike sign being subtracted from the sum of the two given by multiplication of portions of like sign.

In certain types of problems the curves for $f(\lambda)$ and $g(\lambda)$ may have rapid fluctuations. In such a case, to make a mask with a maximum abscissa dimension of eight inches would produce a curve with such steep slopes that the machine would not indicate the result with any reasonable degree of accuracy. Where the accuracy desired warrants the increase in time necessary, the result curve can be obtained in sections of adjacent intervals along the range of the variable parameter. That is, the curves may be extended over an abscissa dimension as great as desired provided the resulting integral is obtained over several intervals each of which has a length not greater than eight inches.

The method of accomplishing this depends upon the fact expressed in the following equations,

$$I(t) = \int_0^t f(\lambda)g(t-\lambda)d\lambda$$
$$= \int_0^a f(\lambda)g(t-\lambda)d\lambda + \int_a^b f(\lambda)g(t-\lambda)d\lambda + \int_b^t f(\lambda)g(t-\lambda)d\lambda. \quad (16)$$

In evaluating the integral the curves are first plotted on a scale such that their geometrical slopes may be readily treated by the machine. The curve is then divided into intervals, o to a, a to b, b to c, $\cdots$ p to t, each eight inches in length. For the interval o to a, the result is obtained as usual. For the interval a to b it is necessary to evaluate two integrals and add the resulting curves as indicated by the equations above. This process of breaking the integral up into sections, all but one of which have fixed limits can be carried on to cover any range of abscissa distance desired, and it is useful in approximating an integral with infinite limits. However, as the number of intervals is increased, the number of curves which must be taken and added for each additional interval increases directly as the number of intervals considered so that a compromise between accuracy and time consumption must be made.

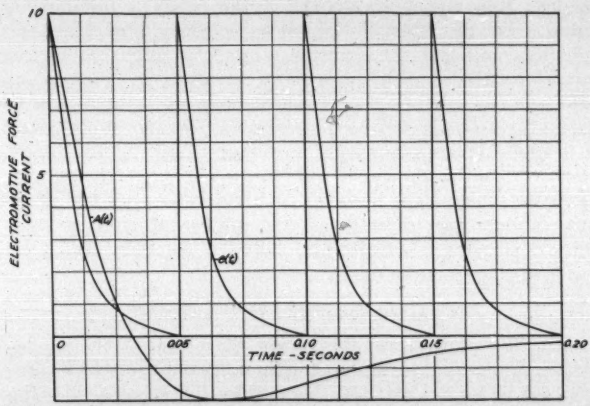
ILLUSTRATIVE EXAMPLES AND APPLICATIONS.

For the purpose of illustrating the scope of the photo-electric integraph, several examples will be given which have been solved by it. In these the machine has been used for the solution of the superposition theorem equation, and the Volterra-type integral equation. In addition it has been applied to correlation problems and periodogram analysis.

As an example of the use of the superposition theorem the analysis of the transient performance of a vacuum-tube amplifier is illustrative. Due to their simplicity, economy in battery supply, and stability, vacuum-tube amplifiers of the resistance-coupled type are sometimes used for the study of electrical transients instead of the direct-current-type amplifier. They are not exactly adapted to this type of work, and it is only by a study of the transient response of the network in the amplifier that the results can be interpreted correctly.

Fig. 8 shows a typical transfer indicial admittance, $A(t)$, of a four-stage resistance-coupled amplifier plotted in arbitrary units of current on the vertical scale. This corresponds to an oscillogram of the current in the output circuit of the amplifier when a suddenly-applied unit voltage is impressed on the input terminals. It is to be noted that an amplifier can give an accurate response to a transient-input voltage only when its transfer indicial admittance rises suddenly and thereafter remains constant. However, by means of the superposition

FIG. 8.

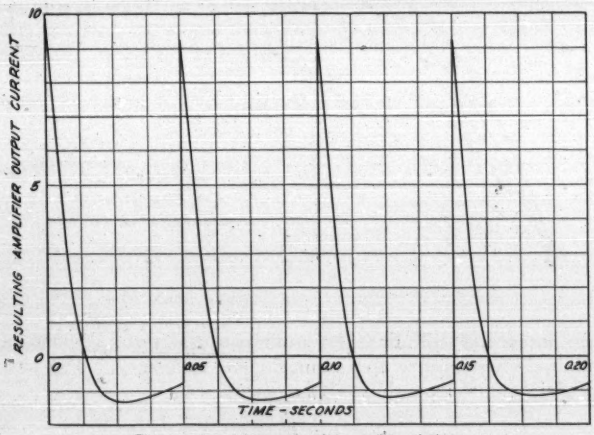


The indicial admittance and an assumed applied voltage of a four-stage resistance-coupled amplifier.

theorem the response of the amplifier to any form of input voltage can be found after the transfer indicial admittance has once been determined. With the use of the superposition theorem, the tacit assumption is made that the circuit is linear. Given the transfer indicial admittance and a knowledge of the output response of the amplifier to an unknown input, it would be possible to find the form of the input transient by means of successively approximating it until the result on the machine conformed with the resulting current from the amplifier.

The particular problem given here as an example concerns the response of the amplifier to a form of input voltage shown at $e(t)$ in Fig. 8. This again is plotted to an arbitrary scale. Equation (3) was chosen as the form of the superposition theorem to be used. One curve for use in the machine was $A'(\lambda)$. It was obtained by plotting the slope of the $A(t)$ curve determined graphically. Due to the fact that this $A'(\lambda)$ curve had both negative and positive values it was necessary to use the method of expression (15) letting k_1 be equal to zero. Thus three masks were made, the first for $A'(\lambda)$, the second for $e(\lambda)$ and the third for a rectangle of height k_2. Two result curves were obtained with the machine, and their scales determined in accordance with the method given previously. The final curve shown in Fig. 9 representing the response of

FIG. 9.



The output current response of the amplifier of Fig. 8.

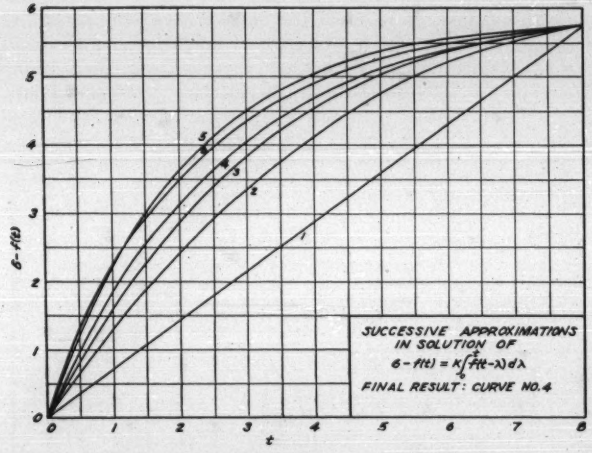
the amplifier to the transient input voltage $e(t)$ was obtained as an algebraic sum of the two result curves and the curve of $e(t)A(0)$ by graphical addition to give

$$i(t) = e(t)A(0) + \int_0^t [A(t-\lambda) + k_2]e(\lambda)d\lambda - k_2\int_0^t e(\lambda)d\lambda,$$

which reduces to the form of the superposition theorem given in equation (3). It clearly shows the distortion introduced by the amplifier and the time necessary for steady-state conditions to be reached. This problem is typical of the many where the data are available in graphical form.

The solution of a Volterra-type integral equation is illustrated by the curves of Figs. 10 and 11. In this equation,

FIG. 10.



Solution of a Volterra-type integral equation by approximations.

the integrand contains the unknown function, so that a method of successive approximations is necessary. The particular equation which was solved was

$$6 - f(t) = k \int_0^t f(t - \lambda) d\lambda,$$

where k is a constant. It was chosen as an example not only to illustrate the rapidity with which the approximations would converge, but also to illustrate the accuracy of the machine, for it has the formal solution

$$f(t) = 6e^{-kt},$$

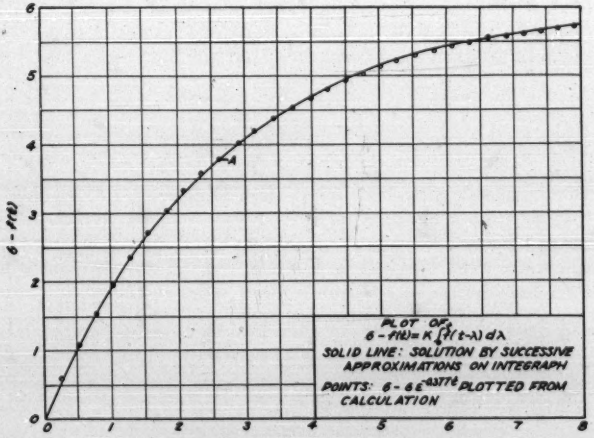
which may be used for comparison. The equation was solved subject to the conditions that

$$f(0) = 6,$$
$$f(8) = 0.25.$$

In Fig. 10 curve No. 1 was arbitrarily taken as the first approximation to the left side of the equation. When the corresponding integrand was placed in the machine, curve No. 2 was obtained as a result. In the same manner when the integrand corresponding to curve No. 2 was placed in the machine, curve No. 3 was obtained, and similarly, curve No. 3 led to curve No. 4. In an attempt to hasten the convergence, curve No. 5 was then chosen arbitrarily and it gave as a result curve No. 6 showing that the correct curve had been passed in the approximate process. When the integrand corresponding to curve No. 6 was placed back in the machine, the resulting curve fell very close to curve No. 4 which was therefore taken as the solution.

Fig. 11 shows curve No. 4 of Fig. 10 with calculated points from the formal solution superposed upon it. The constant k

FIG. 11.

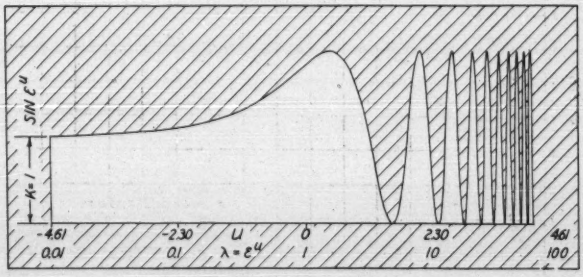


Comparison of result of Fig. 10 with calculated result.

was determined by making the point at A fall on the curve. The accuracy of the instrument in giving the correct shape of curve is set forth by this example. It demonstrates that the precision is sufficiently high to make the device of value in the solution of problems where extreme accuracy is not required and the difficulty of obtaining a formal solution is great.

Due to the restricted physical size of the instrument, limitations are imposed upon the types of functions which can be treated with the Fourier transform given in expression (4) and (5). When the integral is reduced to the form of expression (6), the use of semi-logarithmic coördinate paper becomes convenient. The functions are plotted on this, and are transferred directly to the mask. The mask for sin (e^u) then becomes of the form given in Fig. 12. Here, of course, the constant $k = 1$ has been added to displace the axis and make all the ordinates of positive sign. The method of treating the integral in sections or intervals of the variable of integration outlined previously is applicable here, but it is of less importance for the following reason. The limitation on the range of the variable of integration, u in expression (6), which may be plotted for the mask is not then the 8″ abscissa length of the machine, but is the crowding of the curve toward the upper end of the range of u, as shown in Fig. 12. Doubling the size of the semi-logarithmic paper doubles the range of λ which may be plotted, but the curve extends over

FIG. 12.



Function mask used in the evaluation of the Fourier transform.

more than twice the linear distance. Thus, the curve would have to be treated in three sections, to cover twice the range. Further, to cover four times the range, i.e. use four times the size log paper, would require six sections or intervals, and the gain in range is not proportional to the increase in complexity of manipulation in such a problem. However, the integral formally requires integration over an infinite range. Here again the physical size of the machine limits the application to integrals which converge to a result with sufficient accuracy within the region which can be plotted, and the accuracy obtained depends upon the particular problem.

Since the completion of the photo-electric integraph, considerable unpublished work in the field of correlation analysis has been done by others using it. The principles involved depend upon the following considerations. The Pearson coefficient of correlation, r, is ordinarily defined as follows,

$$r = \frac{\sum_n xy}{n\sigma_x\sigma_y},$$

where x and y are the deviations of the two quantities to be correlated from their arithmetic mean values, n is the number of observed points for each, and σx and σy are the standard deviations given by

$$\sigma x = \sqrt{\frac{\sum_n x^2}{n}} \quad \text{and} \quad \sigma y = \sqrt{\frac{\sum_n y^2}{n}}.$$

If, instead of computations from data, the coefficient of correlation is to be obtained from curves it may be expressed in integral form. The quantities x and y are both functions of a common variable which will be denoted by z, and thus $x = x(z)$ and $y = y(z)$. The coefficient of correlation then becomes

$$r = \operatorname*{Lim}_{A\to\alpha} \frac{\int_0^A x(z)y(z)dz}{\sqrt{\left[\int_0^A x^2(z)dz\right]\left[\int_0^A y^2(z)dz\right]}},$$

where o to A is the range of z over which the quantities are known by graphical plots. The integrals involved do not contain variable parameters, and they are readily evaluated by the Product Integraph.[4] However, in the correlation of quantities which vary with time, such as rainfall and sunspot activity, for instance, one quantity may follow the other after a certain delay or lag in time, and the correlation coefficient becomes a function of this lag, $r(t)$, that is, the problem is to find the lag for the maximum correlation and the value of the correlation coefficient for that lag. Mathematically, the time of the lag, t, enters into the integrals as a variable parameter, and the correlation coefficient becomes

$$r(t) = \operatorname*{Lim}_{A \to \alpha} \frac{\int_0^A x(z)y(z+t)dz}{\sqrt{\left[\int_0^A x^2(z)dz\right]\left[\int_0^A y^2(z)dz\right]}}.$$

Thus the denominator remains fixed and the integral in the numerator involved here is of the form to which the photo-electric integraph is applicable. The determination of the correlation coefficient formally requires integration over an infinite range of data. However, it is sufficient to integrate over a range such that the errors introduced by the finiteness of the data are small compared to those due to other factors, and the accuracy as in most statistical calculations is limited by the amount of data available. The resulting curve of correlation coefficient given by the machine will show a maximum point indicating the value of the maximum correlation, and the elapse or delay in time which must be introduced between the two quantities to obtain this maximum.

Mr. M. M. Bower[10] has applied the photo-electric integraph to the solution of a problem of periodogram analysis. This, a method of finding the hidden periodocities in irregularly varying quantities, has recently been given an extended treatment by Wiener.[2] Essentially the results depend upon

[10] Bower, M. M., "Periodogram Analysis," Master of Science Thesis, M. I. T., 1930.

Kenrick, G. W., in "A New Method of Periodogram Analysis," Doctor of Science Thesis, M. I. T., 1927, made use of the Product Integraph for a point-by-point periodogram analysis of fading phenomena in radio communication.

the evaluation of two integrals, as follows. Let $f(t)$ represent the variations of any quantity with time such as rainfall, river-flow, etc. Then a function, $\phi(u)$ is given by

$$\phi(u) = \lim_{k \to a} \frac{1}{k - u} \int_0^{k-u} f(t) f(t + u) dt.$$

By means of this function $\phi(u)$, a second function $\theta(a)$ is defined as,

$$\theta(a) = \frac{2}{\pi} \int_0^{\infty} \phi(u) \left[\frac{\sin au}{u} \right] du.$$

It may be seen that $\phi(u)$ contains the elements of the correlation of a function against itself, while $\theta(a)$ is obtained from $\phi(u)$ by an integration process similar to that used in the Fourier transform. The significance and importance of the method are based upon the fact that there appears in the curve of $\theta(a)$ a sudden vertical rise for each value of a corresponding to the frequency of a periodic component of $f(t)$, and that the magnitude of the vertical rise is proportional to the square of the amplitude of the periodic component. Phase relations of the components are not given by the method.

By the application of the machine to the analysis of the flow of the Ohio River, Bower obtained indication of periodic components having various amplitudes and frequencies. These when combined by assumptions as to phase relations compared reasonably with the rise and fall of the river. The data for the periodogram analysis was available in the form of gauge readings at weekly intervals over a period of fifty years. The necessarily restricted range of the data reduces the accuracy of the method since the limits of the integrals are infinite, but in general the accuracy is good where the period of the component is small compared to the total range of the data.

To summarize, an instrument has been constructed which has wide application to the solution of mathematical problems because it can be used to evaluate an integral containing a variable parameter. The accuracy which can be obtained by it depends upon the particular problem and the care taken in its use, but may be expressed as from 2 to 5 per cent. Examples given in detail and others outlined point out a few

of its possibilities, and these form the basis of the belief that further use and development will lead to an even more valuable device.

In conclusion, the author wishes to express his appreciation of the interest and suggestions of Professors N. Wiener and A. C. Hardy, and, in particular, the helpful advice, assistance and encouragement of Professor V. Bush. Acknowledgment is also due the Charles A. Coffin Foundation and the Massachusetts Institute of Technology for the fellowship aid given by them which has made the work possible.

NOTES FROM U. S. BUREAU OF STANDARDS.*

TWENTY-FOURTH NATIONAL CONFERENCE ON WEIGHTS AND MEASURES.

The Twenty-Fourth National Conference on Weights and Measures, which met at the bureau on June 2 to 5, was attended by weights and measures officials representing 25 States and the District of Columbia, representatives of scale and pump manufacturers, railroads, and industry. The conference considered and took action on a wide variety of matters directly affecting the buyers and sellers of commodities and services.

The "penny-in-the-slot" scale may not ordinarily be thought of as a device for the selling of service, yet such a scale does represent itself as prepared to render a weighing service for a consideration, and as such it becomes subject to official regulation. One of the actions taken by the conference was the proposal of a code of regulations for these person-weighing scales. Whether the scale passes out a ticket with a weight stamped upon it or whether the customer reads his weight from a chart, the code will require the same clearness and definiteness of the indications and will impose the same restrictions as to permissible errors as in the case of commercial scales used in the weighing of commodities.

Among other subjects considered were a special equipment for the testing of large-capacity oil meters, several forms of trucks carrying from 7,000 to 16,000 pounds of test weights in units of 500 or 1,000 pounds, special scales installed on the highways for determining the actual load on each wheel of a loaded truck so as to prevent overloading and consequent damage to the highways, and various types of gages and gaging utilized in industry to control manufacturing processes.

A number of officials of the Federal Government addressed the meetings. R. S. Regar of the Post Office Department announced a four-year program of his department for the

* Communicated by the Director.

testing, adjustment, and replacement of scales used in the weighing of the mails, in which connection it was stated that "scales are the most important item of supply and equipment in the entire postal service" and that it is apparent that "corrective measures must be taken immediately to protect the revenues of the Government and the interests of the public." The conference was asked by H. A. Spilman of the U. S. Department of Agriculture to consider a proposed bill designed to effect a consolidation of existing Federal legislation relative to baskets, hampers, and barrels for fruits and vegetables, and to correct certain faults which have been found to exist in these laws, particularly interference with State statutes demanding sale of dry commodities by weight. A recent amendment to the Federal Food and Drugs Act was discussed by Dr. W. S. Frisbie, also of the Department of Agriculture; under the new law canned fruits, vegetables, and fish will be considered Standard if they conform to a certain standard of quality and fill, otherwise they must be labeled as Substandard.[1] Dr. Frisbie pointed out that both grades of products will, of course, be required to be entirely wholesome and pure under the general provisions of the Food and Drugs Act. F. S. Holbrook of the Bureau of Standards spoke upon the status of standard-weight legislation for bread; several State laws requiring standard-weight loaves have recently been attacked in the courts by the bakers.

Numerous features of the work of the National Bureau of Standards were discussed by Dr. George K. Burgess, Director of the bureau and president of the conference, who emphasized the diversity and amount of the bureau's testing work. Hon. Charles West, Member of Congress from the 17th Ohio District, urged that a proper balance be maintained between Federal and State regulation along weights and

[1] The form of label prescribed by the Secretary of Agriculture for canned foods of substandard quality is as follows:

BELOW U. S. STANDARD
LOW QUALITY BUT NOT ILLEGAL

It will be understood that cans not so labeled contain foods which are in compliance with the "standard" requirements for quality as defined by the Secretary of Agriculture, and that the contents of the cans occupy 90 per cent. or more of the volume of the can.

measures lines, so that on the one hand interstate commerce might be safeguarded and on the other hand there might be a minimum of encroachment on the rights of the States to regulate their own internal commercial affairs. The methods of weights and measures control in Canada, where the entire service is maintained by the central government of the Dominion, was described to the conference and contrasted with the system followed in the United States, by D. J. McLean, superintendent of the Canadian Weights and Measures Inspection Service.

Other speakers included H. S. Jarrett of Charleston, W. Va., who discussed the marking of all package goods with statements of their net contents; W. O. Williams, of Girard, Ohio, who urged the rigid inspection and testing of all person-weighing scales; A. Bousfield of St. Johnsbury, Vt., who traced the development of large-capacity scales over the past fifty years; M. J. J. Harrison, of Chicago, Ill., who discussed, with particular reference to coal weights, the factors involved in large capacity weighing; De Forest McLin, of Huntington, Ind., who extended a warning against the activities of incompetent, so-called "scale mechanics" who prey upon scale owners particularly in the smaller towns; and C. L. Richard, of Chicago, Ill., who told the Conference of the activities of the National Scale Men's Association, an organization having many interests in common with the Conference.

The conference revised a previously adopted code of regulations for glass bottles used at retail filling stations for dispensing lubricating oil for automobile crank-case use. Certain oil distributors wanted the conference to exempt from the requirements of the code all bottles intended to be marketed as sealed containers, but while the former code was liberalized in some respects, notably by permitting a popular type of tall, small-diameter bottle, it failed to accede to the request for the exemption of sealed bottles, and recommended that both sealed and unsealed bottles be required to have a capacity line and a statement of their capacity blown in the bottle.

A code of regulations for mileage-recording instruments known as odometers was finally adopted, having been tentatively adopted a year ago. It was recommended that after

January 1, 1932, new measuring devices for grease and transmission oil be required to be so designed that whenever the supply of lubricant is exhausted the device will become inoperable as a conspicuous warning will be given that the device is in need of refilling.

The various codes of regulations adopted by the conference do not become effective in most States solely by reason of the conference actions; usually it is not until these codes are promulgated by the State officials, under statutory authority, that their provisions become mandatory. In some States, however, adoption of a code of specifications and tolerances by the conference either automatically or indirectly results in putting such a code into effect.

In connection with the consideration of scale subjects there were exhibited by their manufacturers various scales embodying new features of design and a number of the latest types of person-weighing scales. By resolution, the conference requested manufacturers of small scales to provide special facilities for placing the official seal of approval in a uniform position, so that the customers in retail stores may be the better able to tell when such scales have been approved for use by the weights and measures officer.

Dr. George K. Burgess was reelected president of the Conference. Other officers elected were Albert B. Smith of Harrisburg, Pa., 1st vice president; I. L. Miller of Indianapolis, Ind., 2nd vice president; F. S. Holbrook of the Bureau of Standards, secretary; and George F. Austin, Jr. of Detroit, Mich., treasurer. An executive committee consisting of the officers and of an official from each of twenty States was also elected. The next meeting of the Conference will be held in Washington, D. C., in June, 1932.

METALLURGICAL ADVISORY COMMITTEE.

Scientific research work is well recognized as a form of investment upon which dividends, commensurate at least with the investment made, are naturally to be expected. Research work carried out in government laboratories, like that supported by industry should give adequate returns on the investment.

In order that the metallurgical research work of the bureau may be well planned and efficiently directed along lines which show promise of value and usefulness to the metallurgical industry, an advisory committee was organized a number of years ago. The annual meeting of this committee was held at the bureau on May 19 and 20.

This committee, though strictly unofficial, is believed to be representative of the metallurgical industry. The members have been designated by the various national technical societies among whom are: the American Society for Testing Materials (7); the American Society for Steel Treating (2); the American Foundrymen's Association (3); American Institute of Mining and Metallurgical Engineers, iron and steel division (2); American Association of Steel Manufacturers (2); Society of Automotive Engineers (1); American Institute of Mining and Metallurgical Engineers, institute of metals division (8); American Society of Mechanical Engineers (1); American Electrochemical Society (2); American Chemical Society (1); and National Research Council (1).

The ferrous and the non-ferrous branches consist of 20 members each. In addition, a number of invited guests are included for each meeting whose advice on certain specific problems under way is desired.

Among the current research projects reported upon and discussed at the meetings a few may be mentioned as typical; these are:—Studies of defective steel bridge wire; characteristics of rail steel as related to the formation of transverse fissures; the phenomenon of magnetism in iron as related to atomic structure; the preparation and properties of *pure* iron; the properties of molten metals affecting their casting properties; thermal conductivity of metals; the general problem of the wear of metals; fundamentals involved in the machining of metals; the creep of metals under load at high temperatures; and various aspects of the corrosion of metals.

The committee, is entirely advisory in its scope and while definite recommendations are occasionally made, its greatest value lies in its wholesome influence which has been repeatedly demonstrated during the 18 years which it has been in existence.

PAPER FROM HIGHLY-PURIFIED WOOD FIBERS.

The bureau has been studying on a semi-commercial scale the manufacture of bond types of papers from commercial highly-purified wood fibers. The papers are suitable where strength and permanency are desired. The object of the work was to determine: The quality of paper which can be made from such fibers under favorable conditions; how to obtain this quality; and the extent to which variables commonly encountered in the papermaking process affect the quality of papers made from this type of fiber.

The first phase of the study was concerned with the development of a beating procedure designed to produce papers having the highest possible strength consistent with the other qualities required in saleable commercial papers. By studying the effects of variations in beating conditions on the properties of the papers produced, a method of beating the fibers was evolved which gave the desired results. Since the highly-purified wood fibers hydrated comparatively slowly, it was possible by gradual lowering of the beater roll to avoid the excessive hydration which makes for hardness, low opacity, and low tearing strength, and yet accomplish the fibrillation and fraying out necessary to impart good felting properties to the fibers, so as to obtain the high strength and other properties characteristic of the bond type of paper. Photomicrographs of the beaten fibers show clearly that they are well fibrillated. The papers had excellent strength properties, exceeding, in the case of the bond papers, the strength requirements of the highest grade bond papers purchased by the Government Printing Office, and, in the case of the currency type papers, the strength requirements for United States currency. In the following table, characteristic test data for some of the papers prepared from these fibers are given:

Test Data for Experimental Paper Produced from High-Purified Wood Fiber.

Weight, Thickness and Strength.	Kind of Paper.				
	Unsized.	Bond, Sized in the Beater with 2 per cent. Rosin.	Bond, Sized in the Beater with 1 per cent. Rosin and 5 per cent. Starch.	Bond, Sized in the Beater with ½ per cent. Rosin and Surface Sized with Glue.	Currency, Surface Sized with Glue, No Beater Sizing.
Weight, 25×40, 500 sheets, pounds	57.2	56.2	56.9	57.9	62.6
Thickness, inch	.0040	.0039	.0037	.0037	.0038
Bursting strength, points	45.0	36.5	49.5	53.1	63.2
Folding endurance, double folds:					
Mach	3400	3660	5730	3510	3960
Cross	4380	3290	4270	4320	5400
Tensile breaking strength; kilograms:					
Mach	9.3	9.0	10.9	10.4	——
Cross	6.1	5.4	6.6	7.1	——
Tearing strength, grams:					
Mach	103.2	86.0	98.4	85.0	80.8
Cross	107.6	103.2	110.4	90.2	84.8

These data were obtained in atmospheric conditions of 65 per cent. relative humidity and 70° F. A report containing complete details of this research is being prepared.

DISCOLORATION OF PAPER BY ROSIN.

The bureau, as a part of extensive researches on the preservation of written and printed records, has obtained additional information on the relation of rosin to the yellowing of paper with age. Rosin is employed in record papers as one of the sizing agents necessary for the use of aqueous writing fluids.

The discoloring effect of light upon rosin, and compounds of rosin formed during the rosin sizing of paper was studied, both in air and in an atmosphere of nitrogen, a relatively inert gas. The source of light used was an inclosed carbon arc. The various grades of commercial rosin used in paper; bleached rosin; resinates of sodium, aluminum, and iron; and rosin size contaminated with ferrous and ferric iron, were exposed to the rays of the arc in sealed quartz tubes. The bleached rosin was included because of a patented bleaching process claimed to prevent discoloration of the rosin by light.

The rosins were darkened by the light, even in the inert atmosphere of nitrogen. The bleached rosin darkened to about the same extent as the unbleached. The ferrous resinate was also light sensitive, and an intimate mixture of ferrous resinate and rosin, as found in rosin size contaminated with quantities of ferrous iron smaller than those usually found in industrial waters, was more sensitive to light than rosin alone. The color change of ferrous resinate is probably the result of a photochemical reaction. The ferric resinate, aluminum resinate, and sodium resinate were not light sensitive.

The complete details of this study were published in the May, 1931, issue of the *Bureau of Standards Journal of Research*, as Research Paper No. 307, "The Light Sensitivity of Rosin Paper-Sizing Materials," by Kimberly and Hicks.

Since rosin sized paper contains rosin, ferrous resinate, and rosin size contaminated with ferrous iron, all of which were found to be light sensitive, rosin sizing as currently practiced appears to be detrimental to the preservation of the color of record papers. An attempt will be made to obtain further information on the extent and nature of the effect of rosin sizing materials on the aging properties of papers, by studies of papers to be made in the bureau's mill containing known amounts and kinds of such sizing materials.

CARPET WEAR TESTING MACHINE.

A machine for testing the resistance to wear of carpets and similar floor coverings, when they are subjected to definite wearing forces under controlled conditions, has been developed. The forces are chosen to produce the bending, slipping, twisting, and compression of the pile which takes place when a carpet is walked upon.

A circular sample of the carpet is tacked on a turntable which is brought to bear against two leather covered wheels. One of the wheels is driven by a motor and in turn drives the turntable. The other wheel is used as a brake to produce slipping of both wheels on the carpet as it rotates. A vacuum cleaner removes the material which is worn off. The wear on the carpet is produced by a downward force, a horizontal stress, and a slight twisting motion, all of which have definite values and may be changed if desired. The rate of wear is determined by measuring the change in thickness of the pile of the carpet with a sensitive thickness gage.

The machine can be used to test the relative durability of carpets under definitely specified conditions. Whether the results are a satisfactory measure of probable relative durability of carpets in service has not been determined. The machine should be useful for studies of the effect of various factors on carpet wear and for studies of the relation between the composition and construction of carpets and their resistance to wear.

This machine will be described and some of the results obtained with it discussed in the June issue of the *Bureau of Standards Journal of Research.*

THICKNESS GAGE FOR FABRICS.

A gage has been developed for measuring the thickness of carpets during tests on the carpet wear testing machine. It is believed that the gage will be found suitable for measuring the thickness of other fabrics, since it provides a ready means of measuring thickness under an extremely small known load and under a series of different loads. Thus a measure of the softness or hardness of the fabric can be obtained. The recovery after the application of a load for any period of time

can also be determined readily with this gage and thus the "compressive elasticity" can be evaluated.

The gage consists of a delicately balanced arm on one end of which can be placed a foot of any desired cross-sectional end area of contact. By placing weights on the foot the load on the fabric can be adjusted to suit conditions. The support of the knife edge on which the arm rests can be raised or lowered by means of a micrometer screw. This movement is indicated on a dial which is graduated in thousandths of an inch. The difference in reading obtained when the foot is lowered onto a fabric till the arm just balances and a similar reading obtained with the fabric removed gives the thickness of the fabric.

An illustrated description of this device is included in the paper on the carpet wear testing machine which will appear in the June issue of the *Bureau of Standards Journal of Research.*

Recently a pressure gage has been designed to be used with the thickness tester. By using this gage the thickness can be read directly for any pressure on the fabric from zero to a given maximum. The pressure on the fabric is indicated on a dial, over which moves an indicator actuated by the balance arm of the thickness gage.

CAMERA FOR PHOTOGRAPHING BULLETS.

The special camera, developed sometime ago by Raymond Davis of the bureau for photographing the surface of specimens of pipe, has been adapted to the photographing of the complete surface of bullets or other small cylindrical objects in a single picture. These are photographed at a magnification of ten diameters. This has been made possible by the use of a short focus motion picture lens in conjunction with suitable pulleys so that the speed of the film is now ten times the surface speed of the bullet. The bullets are mounted on the ends of brass rods with wax. A mounting arrangement is provided, whereby the axis of the bullet is brought into line with that of the rod. Pulleys of suitable diameters are provided so that all of the common calibre bullets may be accommodated.

COLOR CORRECTION OF MICROSCOPE LENS SYSTEMS.

In a paper which will appear in the June number of the *Bureau of Standards Journal of Research*, methods are described for the measurement of the lateral chromatic aberration and distortion of microscope objectives and eyepieces. Measurements have been made on 20 apochromatic microscope objectives of four different makes, and on ten compensating eyepieces of two makes. The results show that the compensating eyepieces in general do not entirely compensate for the chromatic aberration of the objectives, and that the complete microscope system is usually undercorrected. The bearing of this on the performance of the system in photomicrographic work by a three color process and in the direct visual observation of objects is considered in detail.

WAIDNER-BURGESS STANDARD OF LIGHT.

The successful setting up in the laboratory of the Waidner-Burgess absolute standard of light was described in Technical News Bulletin No. 151, p. 107 (November, 1929). A paper which will appear in the June number of the *Bureau of Standards Journal of Research* describes the results of experiments in the development of this accurately reproducible light standard. The source of light used is the open end of a small tube closed at the other end and maintained at a definite high temperature. The amount of light emitted from the interior of the tube through the open end is not affected by the material of which the tube is made, but depends only on the temperature. The tube actually used was composed of thorium oxide, a very refractory material, and was kept at a definite and reproducible high temperature by immersing it, closed end down, in a crucible of molten platinum. When the platinum begins to solidify, the immersed tube is at a definite temperature 1774° C. (3224° F.) and remains at this point as long as any liquid platinum is left. The brightness of this source was compared, using a photometer, with the standard electric lamps of the bureau. Many comparisons were made, and it was found that the proposed standard was accurately reproducible. The actual intensity of light from a square centimeter of this source was found to be 58.84 candles.

EXTREME ULTRA-VIOLET SOLAR RADIATION.

A subject widely discussed today is the use for therapeutic purposes of the short wave-length ultra-violet rays in sunlight and in arc lamps, recognized by biologists as possessing healing value, especially in the treatment of rickets.

It has been found that common window glass shuts out some wave-lengths of sunlight that have the property of preventing rickets. Spectrum analysis shows that the constituent shut out by window glass consists of the shortest ultra-violet wave-lengths in sunlight. This constituent or component of the total incident sunlight is greatly reduced by the presence of smoke, dust, etc.

A paper which will be published in the *Bureau of Standards Journal of Research* for June gives data on the variation of the ultra-violet in sunlight, useful for healing purposes, as affected by atmospheric pollution (smoke, etc.), altitude of the station (Washington and Flagstaff, Arizona), humidity of the air, time of the day, and season of the year.

RELATION BETWEEN COMPOSITION AND INDEX OF REFRACTION OF GLASS.

A study of the relation between composition and index of refraction of glass was started some time ago at the bureau and the first phase of this work has been tenatively completed and will be described in the June number of the *Bureau of Standards Journal of Research.* Many glasses were made, containing soda, lime, and silica in various proportions.

The glasses were melted in platinum crucibles placed in a specially constructed furnace which was heated by a controlled current flowing through a platinum-rhodium spiral.

After measuring the index of refraction of 42 of these glasses and making chemical analyses of each of them, an intensive study was made of the data obtained. Finally, a series of curves was drawn from which it is possible to read the index of refraction of any glass of the soda-lime-silica group in the range studied and also to predict the compositions of the numerous glasses having the same index of refraction.

Such work is of particular interest to the manufacturer of optical glass because it indicates the changes that must be made in the composition of a glass to produce a desired change in index of refraction. It should also be useful to the manufacturer of other kinds of glass, such as window glass, as a quick and reliable method of detecting changes in the composition of the glass he is making.

SPECIAL REFRACTORIES FOR USE AT HIGH TEMPERATURES.

In the determination of the physical properties of a pure metal it is usually necessary to melt the metal in order to secure suitable specimens. It is highly desirable that no impurities be introduced into the metal from the crucibles in which it is melted. Crucibles of special oxides or of unusual purity, refractories which are not commercially obtainable, are frequently required. Then too, with the use of the modern electric furnaces, temperatures up to 2000° C. and over are readily obtainable and are more and more frequently used. The refractories ordinarily employed in the commercial melting of metals are not suitable for the melting of very pure metals at these higher temperatures. In the oxides of zirconium, magnesium, thorium, and beryllium there are available refractories which have been used for the melting of metals at temperatures up to 2200° C. (4000° F.) without contamination of the metal by the refractory.

A paper in the June number of the *Bureau of Standards Journal of Research* describes methods for the preparation from these refractory materials of various shapes that are used for the laboratory melting of very pure metals. The refractory oxide mixed with a suitable bonding material is tamped, pressed, or otherwise formed to the required shape and then fired at a temperature which should be somewhat higher than that at which it is subsequently to be used, in order to minimize further sintering and shrinkage in service. Refractory shapes made from previously fused oxides do not shrink appreciably in use.

A sample of pure platinum contained in a crucible of fused thorium oxide was melted and frozen more than 150 times in

the course of a determination of its melting point without loss of any of the metal by leakage through the crucible. The purity of the platinum was practically the same after all these melts as at the beginning.

The method used for fusing the thorium oxide, which has a melting point above 3000° C., is described.

FREEZING POINT OF PLATINUM.

It is well known that the freezing of a pure material takes place at a constant temperature, the most familiar instance being the freezing of water at 0° C. Pure metals also have definite freezing points, which are useful in accurate temperature measurements. One of the more important freezing points is that of platinum, somewhat above 1770° C. In spite of the importance of the platinum freezing point, various determinations of its temperature, even those made in recent years, have differed by nearly 10° C. The bureau has recently made another determination of this freezing point and found it to be 1773.5° C. (3224° F.) which is believed to be correct within about 1° C.

The platinum is melted in a small crucible, in the middle of which is a tube, less than 1/8 inch in diameter, immersed in the melted platinum. The light coming from this tube, not that from the platinum itself, is observed with an optical pyrometer. In making an observation, the platinum is melted, and the liquid heated somewhat above its melting point, and is then allowed to cool slowly. The observer notices that the brightness decreases slowly until freezing begins, when the brightness does not change for several minutes. After freezing is completed the brightness again decreases.

Even a few years ago the measurements described would not have been possible. It was necessary to prepare crucibles of thorium oxide in which the platinum could be melted without contamination by the crucible material. Melting was done in an induction furnace which operates so as to cause a heavy electric current to flow in the platinum itself without using any connecting wires, and nothing is heated except the platinum and the crucible containing it. A very accurate

optical pyrometer designed at the bureau was used. Since only a small specimen of platinum is needed the value of the metal was not over $200. One ingot was melted nearly 100 times, and many hundreds of observations were made of the temperature of freezing. Much care and numerous observations were necessary to obtain a result which might be considered reliable within a few degrees.

This work will be more fully described in the June number of the *Bureau of Standards Journal of Research.*

METHODS FOR CLASSIFYING WEAR OF METALS.

Wear of metals and methods for classifying it, will be discussed by Louis Jordan of the Bureau of Standards in the August number of *Mechanical Engineering*, published by the American Society of Mechanical Engineers, June first to third.

Wear of a metal is the unintentional removal in service of the surface of a metal through the action of frictional forces. The different types of metallic wear have been classified as metal against metal and metal against nonmetal; or as wear under rolling friction and wear under sliding friction. A more logical classification is on the basis of the physical and chemical actions at the surface of wearing metals, namely: Wear by abrasion, in which the wear is caused entirely by mechanical roughening and rubbing off of the metal surface; wear by erosion in which a chemical attack of the metal surface first takes place, followed by mechanical rubbing of the products of the chemical attack; and wear by galling in which localized areas of metal surfaces in contact "weld" together and particles are torn off the original surface of one or the other of the bearing parts.

In methods of guarding against wear, lubrication stands first of all. With complete and efficient lubrication, wear is negligible. When lubrication is inefficient or cannot be used other means of preventing wear must be employed. Ball and roller bearings, and white metal alloy and bronze bearing metals are widely used as a second line of defense against failure of lubrication. Methods of producing very hard surfaces on relatively soft metals are case hardening and

nitriding of steel, chromium plating, and surface layer welding. For some types of service the "super hard" alloys such as "stellite" and sintered tungsten carbide are becoming more widely used. The hardness of these latter alloys approaches that of the diamond.

There are a number of laboratory methods applicable to the testing of the wear resistance of metals but it is at present difficult or even impossible to translate the laboratory data into the terms of probable life of actual service.

ENDURANCE TESTING OF STEEL.

The bureau is engaged in an extensive study of the properties of rail steels. One phase of the investigation is the determination of the endurance limits of this material, with the object of ascertaining, if possible, to what extent the resistance of a rail to the repeated stresses to which it is subjected in service may be related to the non-metallic inclusions or "dirt" and other unsound conditions in the steel. To determine which method of test would be the most discriminating in showing the effects of such inclusions and other unsound conditions in the steel upon the endurance properties, comparisons were made between the rotating-beam and the axial-loading methods for the determination of endurance limits.

The materials used for the comparative tests were an open-hearth iron containing 0.02 per cent. carbon; wrought iron in three stages of refinement by rolling; three plain carbon steels containing 0.45, 0.47 and 0.87 per cent. carbon, respectively, and each tested in both the annealed and in the heat-treated conditions; and four rail steels.

In no case was the endurance limit determined by the axial-loading method greater than that determined by the rotating-beam method. For the 0.45 per cent. carbon and the 0.87 per cent. carbon steels in the heat-treated condition the endurance limits were practically the same by both methods of test. The indications, in general, were that for a non-uniform material the endurance limit in axial loading is lower than it is when determined by the rotating-beam method.

IMPROVED MERCURY MANOMETER AND PISTON GAUGES FOR MEASURING PRESSURE DIFFERENCES.

In power plants, steam and other substances are used as media to convert heat into mechanical power; in refrigerating plants, numerous substances such as ammonia, carbon dioxide, sulphur dioxide, and methyl chloride, are used to convert mechanical power into cooling effect. These media possess certain properties on which accurate data are of prime importance to the power plant and the refrigerating engineer. The acquirement of these data necessitates accurate pressure measurements. For this purpose a differential mercury manometer for pressure differences up to 15 atmospheres (about 220 lbs./in.^{2}), and a group of piston gauges for pressures up to 100 atmospheres (about 1500 lbs./in.^{2}) have been constructed and maintained at the bureau. These instruments will be described and their accuracy discussed in a paper to be published in the June number of the *Bureau of Standards Journal of Research*.

The manometer, instead of being constructed in the form of a single column or a single U-shaped tube, consists of five U tubes connected in series; the instrument in this form is of such reduced height that it may be housed in one room. The lower halves of the U tubes are filled with mercury, the upper halves with water. A pressure applied at the left-hand end of the manometer causes a simultaneous depression of the mercury and water in the left-hand branches of the U tubes and a corresponding rise of these fluids in the right-hand branches. The applied pressure is determined by observing the positions of the various mercury surfaces and calculating the sum of the difference in heights between the surfaces in the right- and those in the left-hand branches. Pressures can be measured with this manometer with an accuracy of about one part in 10,000.

Each piston gauge consists of a steel piston movable vertically inside a steel cylinder. This piston is rotated in order to reduce frictional forces which hinder the vertical movement. Oil is used to lubricate the gauge and to transmit the observed pressure to the bottom of the piston. This transmitted pressure is measured by adjusting the weights supported by the piston until there is no vertical movement.

The pressure may then be calculated in any desired units by multiplying the combined weight of the piston and its load by the appropriate factor. The value of this factor may be determined from the measurements of the piston diameter and the width of crevice between the piston and cylinder, in which case the gauge is said to be an absolute or primary instrument; or it may be determined from a comparison of the piston gauge with a mercury manometer, in which case the manometer is said to be the primary instrument, and the piston guage is a secondary instrument. When used as primary instruments, the piston gauges at the Bureau of Standards are accurate to within two or three parts in 10,000; when used as secondary instruments, they are as accurate as the manometer, namely, to about one part in 10,000.

THE FRANKLIN INSTITUTE.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, June 10, 1931.)

HALL OF THE COMMITTEE,
PHILADELPHIA, JUNE 10, 1931.

MR. LIONEL F. LEVY *in the Chair.*

The following reports were presented for final action:

No. 2838: Paulin Altimeter.

This report recommended the award of the Edward Longstreth Medal to Mr. Josua Gabriel Paulin, of Stockholm, Sweden, "In consideration of the invention of a form of barometer with which difference in elevation can be quickly determined."

No. 2927: Electric Flow Meter.

This report recommended the award of the Certificate of Merit to Mr. Thomas R. Harrison, of Philadelphia, Pennsylvania, "In consideration of the improvements made in an electric flow meter, containing several conveniences which render it a highly flexible and adaptable instrument."

GEO. A. HOADLEY,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, June 17, 1931.)

RESIDENT.

MR. HAROLD T. SEELEY, Designing Engineer, General Electric Company, 6901 Elmwood Avenue, Philadelphia, Pa. For mailing: 512 Orchard Avenue, Yeadon, Pa.

NECROLOGY.

Mr. Cyrus N. Anderson, Narberth, Pa.
Mr. Harrington Emerson, New York City.
Miss Emily E. Howson, Decatur, Ga.
Mr. O. C. Skinner, Burnham, Pa.

CHANGES OF ADDRESS.

MR. WALTER ATLEE, 924 Cathedral Street, Baltimore, Maryland.
DR. JAMES BARNES, The Franklin Institute, 15 South Seventh Street, Philadelphia, Pa.
MR. ONWARD BATES, 832 Belden Avenue, Chicago, Ill.
MR. J. C. DACOSTA, 3D, Meadland, Three Gates Lane, Haslemere, Surrey, England.
MR. W. A. DOBSON, 56 South Fairway, North Glenside, Pa.
MR. E. D. DOYLE, Patent Engineer, Leeds and Northrup Company, 4901 Stenton Avenue, Philadelphia, Pa.
MR. WALTER B. FERGUSON, Germantown Manor, Philadelphia, Pa.
DR. F. W. FRERICH, 12 Kimball Road, East Lynn, Mass.
MR. NEVIN E. FUNK, 715 Panmure Road, Haverford, Pa.
DR. CHARLES H. LAWALL, 214 South Twelfth Street, Philadelphia, Pa.
MR. ROBERT LEBOUTILLIER, 417 North Wayne Avenue, Wayne, Pa.
MR. GEORGE W. LEWIS, 6502 Ridgewood Avenue, Chevy Chase, Maryland.
MR. C. B. NEBLETTE, 39 Lakeview Park, Rochester, N. Y.
REAR ADMIRAL WILLIAM S. SIMS, U.S.N., Marion, Mass.
MR. KELVIN SMITH, 3077 Huntington Road, Staten Heights, Cleveland, Ohio.
MR. SIGURD WESTBERG, 43 Tuttle Place, East Haven, Conn.

LIBRARY NOTES.

RECENT ADDITIONS.

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DEFANT, A. Einführung in die Geophysik: III—Dynamische Oceanographie. 1929.
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FRETS, G. P. Alcohol and the Other Germ Poisons. 1931.
HACKH, INGO W. D. Structure Symbols of Organic Compounds. 1931.
HAGUE, B. Alternating Current Bridge Methods. 1930.
HAMILTON, SIR WILLIAM ROWAN. Mathematical Papers. Volume I: Geometrical Optics. Edited for the Royal Irish Academy by A. W. Conway and J. L. Synge. 1931.
Jahresbericht über die Leistungen der chemischen Technologie für das Jahr 1930. 76 Jahrgang, 1 Abteilung: unorganischer Teil. 1931.
KAYSER, H., AND H. KONEN. Handbuch der Spectroscopie. Siebenter Band, Zweite Lieferung. 1930.

NIPPOLDT, A., J. KERÄNEN, UND E. SCHWEIDLER. Einführung in die Geophysik: II, Erdmagnetismus und Polarlicht, Wärme-und Temperaturverhältnisse der obersten, Bodenschichten, Luftelektrizität. 1929.

Penrose's Annual: the Year's Progress in the Graphic Arts. Volume 32. 1930.

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BOOK REVIEWS.

STRUCTURE SYMBOLS OF ORGANIC COMPOUNDS, An adjunct to text books of organic chemistry for students and teachers, by Ingo W. D. Hackh, author of "A Chemical Dictionary" and "Chemical Reactions and Their Equations." viii–139 pages, 12mo. Philadelphia, P. Blakiston's Son & Co., Inc. Price $2.50.

By virtue of their easy familiarity with the countless members of the graphic formula family, organic chemists have been able to acquire a degree of exclusiveness which is not equalled by the followers of any other branch of chemistry; the author will not allow such exclusiveness to lessen. With the express purpose of aiding the noviciates in assimilating the exotic lore of organic chemistry, Dr. Hackh has evolved a system which is a simplification of the present graphic formulary yet uses hieroglyphics of a nature more strange. Perhaps our very remote ancestors were not so dumb when they inscribed a particular character for each object. The characters in this new system for depicting organic compounds graphically remind one of Chinese in some instances and the picture writing of the savages in others. If one had the time, he might pick out many a symbol whose form very appropriately indicated the nature of the compound it represented. In passing we can only remark that the symbols for the various sugars remind one of railway signal towers; for oxalic acid, a glorified capital H; for stearic acid, a centipede and for tyrosine, the Vassar daisy chain.

Chapter one is given in the form of an introduction and discusses in a general way the properties of atoms and molecules from the standpoint of valence, electronic arrangement, polarity and molecular structure. Chapter two gives a lucid description of the author's system of structural symbols for organic compounds. It is remarkably simple and logically constructed. The student should have comparatively little trouble in mastering it, but probably will not appreciate its advantages if he has not made the acquaintance of the former very serviceable but more cumbersome method. Chapter three is merely a list of nearly one thousand organic compounds accompanied by their symbols.

T. K. CLEVELAND.

COURS DE PHYSIQUE DE L'ECOLE POLYTECHNIQUE, par M. A. Lafay, Professeur. Tome I. Acoustique-Electricite, 666 pages, quarto, paper, 1930. Price 125 francs. Tome II. Thermodynamique-Optique, 736 pages, quarto, paper, 1931. Paris, Gauthier-Villars et Cie. Price 150 francs.

The Ecole Polytechnique has long been one of the strongholds of French technical education, and the name of that institution on the title page of a text-

book is always suggestive of a hall-mark of technical quality. The reader will not be disappointed either in the deductive and analytical character of the work or in its diversity of representative material. In this *cours*, that fundamental division of physics which we know as "mechanics" is conspicuous by its absence. The Polytechnician embarks upon this subject-matter evidently previously well prepared by his *cours de mecanique* as he must be in his *cours d'analyse* if he is to complete the programme of this voluminous work within the possible time that may be allotted to it in a three years course of study.

Volume I—acoustics and electricity—is in thirty-one chapters or *leçons*, doubtless so termed in harmony with the amount of ground to be covered in a recitation or lecture period. These chapters are often followed by a *complément* or addendum in which the topic is further extended. The first two chapters contain a discussion of the properties of materials under stresses of extension, compression and torsion, and include a consideration of the elastic deformations in isotropic bodies laterally with respect to longitudinal displacement. Simple and damped periodic motion are also introduced here with an account of Coulomb's experiments on torsion. Other topics like the elasticity of fluids and viscosity harmonize well with the others of this introductory matter.

Acoustics which ends with the sixth chapter covers the usual elements of the production of sound and the methods of its analysis and measurement. There are no illustrations of apparatus except in diagrammatic form throughout the work, but these are quite adequate to the purpose. In a note on sound direction finders, there is a reference to the twin stethoscope-like instrument known as the "geophone" which received extensive application during the world war in determining the location of enemy sapping operations. As in earlier descriptions, the name of the originator of this useful instrument is omitted.

The remaining twenty-five chapters are wholly occupied in a development of the elements of electricity and magnetism, the treatment being in conformity with the usual modern texts. Here again the diagrammatic illustrations are a convincing help to the terse and logical demonstrations which are models of a scientific text. Especially in the treatment of the electrostatic and electromagnetic induction will that quality be appreciated. Electric oscillations, cathodic rays, x-rays, ionization, the electron and like topics are treated in the concluding chapters.

In the second volume, thermodynamics and optics, no less than in dealing with the subject-matter of the first volume, the author makes certain of building upon a firm foundation. He sets forth at length the first principle of energy and its application to the study of the properties of gases in the most general terms, specific heats, and in that connection, the velocity of sound in fluids. Continuing the development there are discussed at most ample length the internal energy of fluids, the liquefaction and flow of gases, the principle of Carnot and the entropy integral of Clausius, and their application. Two lengthy chapters on actual thermodynamic transformations are followed by the three closing chapters, thermic engines, kinetic theory of gases, the investigations of Maxwell and Boltzmann, and the work of Fourier and others on thermic conduction.

The section of optics maintains the high standard of analytic treatment of the preceding sections and if it differs at all from the others as to including everything of importance in the art, it is even more exhaustive. On the velocity

of light, the work of Roemer, Bradley, Fizeau, Cornu, and Foucault is examined fully. The evolution of the theory of interference of luminous waves is woven about the work of Newton, Young and Fresnel. The phenomena of diffraction are dominated by the principle of Huyghens and again by Newton, Fresnel and Cornu, and in later investigations, Fraunhofer, Rutherford, Rowland and Fabry and Perot. On the applications of interference the work of Michelson and that of Fabry and Perot are naturally given important consideration. The Döppler principle as applied to light propagation, the early work of Fresnel and the relatively recent classics of Michelson and Morley and Lorentz are examined critically, and then follows a lengthy chapter on the elusive subject of relativity. Polarization, double refraction, elliptic and circular polarization, chromatic polarization and rotary polarization are most fully analyzed. We are again brought into the field of recent activity with spectrum analysis, absorption spectra, Zeeman effect, actinometry, and the methods of color photography of Lippman and Lumiere. A further advance into this territory is made with a consideration of the infra-red spectrum, phosphorescence, Raman effect, black body radiation, radioactivity, optics of x-rays and photo-electric effect.

The work is a remarkably well correlated and comprehensive collection of the phenomena of physics treated with rare lucidity by methods of the mathematical physicist.

L. E. P.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 377. A Method of Flight Measurement of Spins, by Hartley A. Soule and Nathan F. Scudder, 18 pages, illustrations, quarto. Washington, Government Printing Office, 1931, price ten cents.

A method is described involving the use of recording turn meters and accelerometers and a sensitive altimeter, by means of which all of the physical quantities necessary for the complete determination of the flight path, motion, attitude, forces, and couples of a fully developed spin can be obtained in flight. Data are given for several spins of two training type airplanes which indicate that the accuracy of the results obtained with the method is satisfactory.

The method was developed by the National Advisory Committee for Aeronautics at Langley Field as a part of a general study of the phenomenon of spinning. It is now being used in an investigation to determine how the spinning characteristics of several airplanes are affected by various changes in their inertia and geometric characteristics. A study is being made to extend the method to include measurements during the entry and recovery from a spin as well as during the fully developed spin.

Report No. 380. Pressure Distribution over the Fuselage of a PW-9 Pursuit Airplane in Flight, by Richard V. Rhode and Eugene E. Lundquist, 29 pages, illustrations, quarto. Washington, Government Printing Office, 1931, price twenty cents.

This report presents the results obtained from pressure distribution tests on the fuselage of a PW-9 pursuit airplane in a number of conditions of flight. The investigation was made to determine the contribution of the fuselage to the total lift in conditions considered critical for the wing structure, and also to determine

whether the fuselage loads acting simultaneously with the maximum tail loads were of such a character as to be of concern with respect to the structural design of other parts of the airplane. The tests were conducted by the National Advisory Committee for Aeronautics at Langley Field, Va., during the spring of 1929.

The results show that the contribution of the fuselage toward the total lift is small on this airplane, ranging from slightly less than 3 per cent. at the lower angles of attack to about 4 per cent. at the higher angles, which approximately compensates for the portion of the wing area replaced by the fuselage. Aerodynamic loads on the fuselage are, in general, unimportant from the structural viewpoint, and in most cases they are of such character that, if neglected, a conservative design results. In spins, aerodynamic forces on the fuselage produce diving moments of appreciable magnitude and yawing moments of small magnitude, but opposing the rotation of the airplane.

A table of cowling pressures for various maneuvers is included in the report.

TELEPHONE THEORY AND PRACTICE-THEORY AND ELEMENTS. By Kempster B. Miller. 492 pages. 272 illustrations, 8vo. New York, McGraw-Hill Book Co., 1930. Price $5.00.

"Telephone Theory and Practice" sounds like a complicated and highly technical subject. Under the skilful authorship of Kempster B. Miller, however, it becomes thoroughly interesting and not difficult to understand even for an untrained reader. The volume under consideration is the first of three which are intended to take the place of his "American Telephone Practice" which was last revised in 1906.

This volume divides itself naturally into three parts. Chapters 1–4 give an interesting survey of the history of the development of speech transmission from earliest times. They contain a discussion of the various devices which precede the electric speaking telephone and an unusually authentic history of that instrument. The second part of the volume, Chapters 5–10 inclusive, contain an exceptionally accurate discussion of the elementary theory of The Vibrations of Sound, The Sensations of Sound, The Kinds of Sound, Voice Currents, Vacuum Tube Theory, and Magnetic Materials. The most striking feature of the book is the skill with which Mr. Miller has given an accurate and thoroughly understandable discussion of these topics in a manner so elementary that they should present no difficulties to any intelligent reader however untrained he may be in modern physics. These chapters are written practically without mathematics with the exception of a very few equations which are written in primarily for reference, and might well be omitted by the reader who does not understand them.

The author has recognized the lack of an adequate treatment of acoustics in connection with telephony and has supplied an excellent discussion of this phase of telephony. In this treatment the more important results of a large number of investigations on the manner of operation of the ear and vocal organs, the properties of sound necessary to intelligibility, the phenomena of masking, and of subjective tones, the definition, meaning and use of pitch and loudness units are clearly set forth.

The chapter on vacuum tubes presents clear pictures of the action of these devices in their various rôles. The discussion of magnetic materials concerns

itself primarily with the properties of the iron-nickel-cobalt alloys which have found such wide application recently in communication apparatus.

The last part of the book, Chapters 11–16 inclusive, is devoted to elements of apparatus. The chapter headings are Wires for Equipment Use, Coils and Electromagnets, Resistors, Condensers, Flexible Cords, Joints and Contacts. The importance of these units, though perhaps minor from the point of view of scientific interest, can hardly be overestimated from the point of view of successful operation of the enormously complicated modern telephone systems.

The book is excellently printed and illustrated, and references to primary sources for those who wish to explore the subject more in detail are frequent and well chosen. The author needs no introduction to the older workers in the telephone art, having long been an authority in his field. His clear and interesting style make the book easy and pleasant reading, and his historical outline as well as his treatment of acoustics should be of wide general interest.

HENRY G. GALE.

ASTRONOMY. By Forest Ray Moulton, Ph.D., D.Sc., xxiii–549 pages, with 213 figures and six star maps, 8vo. New York, The Macmillan Company, 1931. Price $3.75.

When, a few years ago, Dr. Moulton retired from his professorship in the University of Chicago to assume an executive position with a Chicago public utility, astronomers generally felt considerable regret that their distinguished colleague was apparently forsaking his science. The appearance of this book, therefore, is doubly welcome. Not only is it an excellent general work on the subject but it shows that Dr. Moulton has not given up astronomy entirely.

After a preliminary chapter on some general considerations, including remarks about the scope of astronomy, the author starts out with the constellations themselves. Then follows an account of the telescopes used by astronomers to observe the heavens, and a discussion of the Earth itself, its motions, and the measurement of time. This leads to the Moon, eclipses, the solar system as a whole, the individual planets, meteors and comets, and then to the Sun, as a typical star. After a chapter on the evolution of the solar system, a subject on which the author is an outstanding authority, he deals with the stars and nebulae, and concludes with a chapter on the sidereal structure. To the reviewer, this seems to be a most logical arrangement, going from the most familiar part of astronomy, the stars themselves and the Earth, to the more remote and unfamiliar objects.

As might be anticipated, the chapter on the evolution of the solar system is particularly interesting. Here Dr. Moulton gives the latest outline of the planetesimal theory with which his name and that of his former colleague, the late Professor T. C. Chamberlin, are so inseparably linked. The chapter on meteors and comets also contains some of the latest information, as this is a subject to which the author has devoted considerable time in recent years.

New theories are treated with a neutrality that is commendable in an elementary work of this kind. In referring to the theory of relativity, for instance, Dr. Moulton concludes that "Einstein's theory is explicit only in the infinitesimal and that there are many solutions of his equations in the large. As an illustration of possible varieties Einstein has one solution of his equation coming to the conclusion that space is finite, while W. DeSitter has quite another one in which

it is infinite. There is nothing in the theory of relativity that compels a person to accept either of these solutions of this fundamental equation." In the concluding chapter, however, the author expresses his own opinion very definitely. "Our universe is infinite in space and, as a little examination shows, in the number of its stars, and of its galaxies, and of its super galaxies of every order," he states.

Though excellent, on the whole, in a few respects the book does not seem fully up to date. For instance, on page 352, in describing the study of the flash spectrum at total solar eclipses, he refers only to the use of the slit spectrograph, though practically all present day observers employ the slitless instrument because of its many advantages. While the spectrohelioscope is mentioned in the index; on page 371, to which reference is made, only the spectroheliograph is described and no account whatever is given of Dr. Hale's newer instrument with which many valuable observations are now being made. Oppolzer's monumental "Canon der Finsternisse" is stated, on page 205, to be out of print, though a reprint has been available in recent years. Probably it was intended to give greater convenience, but the reviewer feels that the practice of dividing the index into three parts, one of names, another of stars and nebulae, and the third of general references, is decidedly disadvantageous. One straight alphabetical list is much more convenient. Typographically, the book is all that would be expected in the product of so prominent a publishing house. The printing and the illustrations are excellent, as are the six star maps, which follow the recently adopted constellation outlines of the International Astronomical Union. The book may therefore be highly recommended to anyone wanting the latest elementary work on astronomy.

JAMES STOKLEY.

PUBLICATIONS RECEIVED.

Annual Survey of American Chemistry, Volume V, 1930. Edited by Clarence J. West, National Research Council, 629 pages, 12mo. New York, Chemical Catalog Company, 1931. Price $5.00.

Opticks or a Treatise of the Reflections, Refractions, Inflections and Colours of Light, by Isaac Newton, reprinted from the fourth edition with a foreword by Prof. Albert Einstein, Nobel Laureate and with an introduction by Prof. F. E. Whittaker, 414 pages, illustrations, 12mo. New York, Whittlesey House, 1931. Price $2.50.

A Short History of Atomism from Democritus to Bohr, by Joshua C. Gregory, 258 pages, illustrations, 8vo. London, A. C. Black, New York, Macmillan & Co., 1931. Price $3.50.

A Textbook of Inorganic Chemistry, edited by J. Newton Friend, Volume VII, Part II, sulphur selenium and tellurium, by Reece H. Vallance, Douglas F. Twiss and Miss Annie R. Russell, London, Griffin & Co., Philadelphia, J. B. Lippincott Co., 1931.

Encyclopedie Photometrique. Cinquieme section—Mesures sur l'Emission, IV. Traite de Pyrometrie Optique, par Gustave Ribaud. Preface de M. Charles Fabry, 485 pages, illustrations, 8vo. Paris, Revue d'Optique, 1931. Price 95 francs.

Seeing, A Partnership of Lighting and Vision, by M. Luckiesh, D.Sc. and Frank K. Moss, E.E. 251 pages, diagrams, plates, tables, 8vo. Baltimore, The Williams & Wilkins Company, 1931. Price $5.00.

Faraday, Life and Work, 133 pages, portrait, 8vo. London, The British Electrical and Allied Manufacturers Association, 1931. Price 7s. 6d.

A Life of Joseph Priestley, by Anne Holt, with an introduction by Francis W. Hirst, 221 pages, 12mo. London, Oxford University Press, 1931. Price $3.50.

Educational Views of Benjamin Franklin, edited by Thomas Woody, 270 pages, 12mo. New York, McGraw-Hill Book Company, Inc., 1931. Price $2.00.

Industrial Organization, by Harry Rubey, B.S., C.E. 308 pages, tables, diagrams, 8vo. Boston, Ginn & Co., n.d. Price $2.80.

The First Course in Quantitative Analysis, containing a group of lectures and laboratory experiments, by Floyd Hamilton Fish, M.S., Ch.E., 120 pages, 12mo. Philadelphia, P. Blakiston's Son & Co., Inc., n.d. Price $1.25.

Canada, Department of Mines, Mines Branch:

Investigations of Mineral Resources and the Mining Industry, 1929, 69 pages, plates, tables, diagrams, 8vo. Ottawa, King's Printer, 1930.

Investigations in Ore Dressing and Metallurgy, 1929, 208 pages, tables, 8vo. Ottawa, King's Printer, 1931.

Measurement Units and Standards, Spring edition, 1931, 32 pages, 8vo. New York, American Institute of Weights and Measures.

U. S. Department of Commerce, Bureau of Mines, Tin in 1929, by Charles White Merrill, Mineral Resources of the United States, 1929, Part I, pages 333–362, tables, 8vo. Washington, Government Printing Office, 1931.

Phosphate Rock in 1929, Mineral Resources of the United States, 1929, Part II, pages 341–357, tables, 8vo. Washington, Government Printing Office, 1931.

National Advisory Committee for Aeronautics. Technical Notes, No. 376, Effect of High Air Velocities on the Distribution and Penetration of a Fuel Spray, by A. M. Rothrock, Langley Memorial Aeronautical Laboratory, 9 pages, diagrams, plates, quarto. Washington, Committee, 1931. No. 377, An Integrating Manometer for Use in Wind Tunnel Pressure Distribution Measurements, by Richard W. Noyes, Langley Memorial Aeronautical Laboratory, 6 pages, plates, quarto. Washington, Committee, 1931. No. 378. Comparison of Weights of 17st and Steel Tubular Structural Members used in Aircraft Construction, by E. C. Hartmann, Aluminum Research Laboratories, 17 pages, diagrams, quarto. Washington, Committee, 1931. No. 379, The Pressure Distribution over a Semicircular Wing Tip on a Biplane in Flight, by Richard V. Rhode and Eugene E. Lundquist, Langley Memorial Aeronautical Laboratory, 14 pages, diagrams, tables, quarto. Washington, Committee, 1931. No. 380, A Suggested Method for Measuring Turbulence, by C. Fayette Taylor, 7 pages, diagrams, quarto. Washington, Committee, 1931. No. 381, Endurance and other Properties at Low Temperatures of Some Alloys for Aircraft Use, by H. W. Russell and W. A. Welcker, Jr., Battelle Memorial Institute, 16 pages, tables, plates, diagrams, quarto. Washington, Committee, 1931.

Bell Telephone Laboratories, Monographs: No. B-551, Absolute Amplitudes and Spectra of Certain Musical Instruments and Orchestras, by L. J. Sivian, H. K. Dunn and S. D. White, 42 pages, diagrams, 8vo. B-552, Formation of

Photographic Images on Cathodes of Alkali Metal Photoelectric Cells, by A. R. Olpin and G. R. Stilwell, 5 pages, illustrations, 8vo. B-558, Optical Properties of a Lippmann Lenticulated Sheet, by Herbert E. Ives, 6 pages, diagrams, 8vo. B-559, A Modern Laboratory for the Study of Sound Picture Problems, by T. E. Shea, 9 pages, illustrations, 8vo. B-561, Automatic Power Plants for Telephone Offices, by R. L. Young and R. L. Lunsford, 33 pages, illustrations, 8vo. B-562, A Rapid Method of Estimating the Signal-to-Noise Ratio of a High Gain Receiver, by F. B. Llewellyn, 5 pages, 8vo, New York, 1931.

CURRENT TOPICS.

Thomas Young's Place in the History of the Wave Theory of Light. HENRY CREW. (*Journal of the Optical Society of America*, Jan., 1930.) This paper by the distinguished Professor of Physics at Northwestern University was presented at the Thomas Young Memorial Session of the Optical Society of America on October 24, 1929. It deals chiefly with the conflict between the wave theory and the corpuscular theory of light in the interval from 1801 to 1829, the year of Young's death. Professor Crew depicts first the condition of optical theory at the close of the eighteenth century. It is not known who was the first to suggest the wave theory of light. Hooke, though not claiming to originate the idea, in 1665 claimed that light is vibrative, short and quick. In the quarter-century that followed three facts were discovered that had to be reckoned with by any satisfactory theory. Bartholinus in 1669 discovered double refraction, Römer in 1675 showed that light has a finite velocity, and Huyghens came upon the polarization of light by placing one crystal of Iceland spar on another. Huyghens in 1690 suggested that light is made up of pulses, longitudinal pulses, that move outward from any luminous source in an isotropic medium. He seems to have thought only of pulses and not at all of a succession of waves. The debt of Physics to Huyghens is thus stated: "We owe to him a clear conception of the wavefront as the envelope of an infinite number of elementary waves; the immensely valuable idea that one can substitute for an actual point source of light a distribution of suitable point-sources over a surface enveloping the actual point-source; an idea which led, in later hands, directly to the explanation of the rectilinear propagation of light and of a host of other diffraction phenomena. But the marvellous competence of Huyghens' wave-form in describing the facts of double refraction in crystals places its value beyond question." He could not, however, explain the polarization of light.

Newton, whose book on Opticks appeared in 1704 presented two theories of light, the corpuscular and the wave theory. He could not reconcile the latter with the rectilinear propagation of light. His chief contribution to optics consisted of his investigations of prismatic spectra, of the colors of thin plates and of diffraction between two knife edges. Half a century after Newton came Euler, a champion of the wave theory, making much of the similarity

between light and sound. He himself recognized that he made no real contribution to optics. At the close of the eighteenth century neither the pulses of Huyghens nor the corpuscles of Newton could be regarded as satisfactory explanations of the ascertained facts of light.

In November, 1801, Thomas Young gave a Bakerian Lecture before the Royal Society in which he discussed the interference of light. Soon afterwards he laid down as conditions of light interference that the two rays must come from the same source and must reach the same point by different paths whose directions must deviate only a little from each other. He offered simple experimental evidence for the existence of interference. "This simple but tremendously important fact that two rays of light incident upon a single point can be added together to produce darkness is, as I see it, the one outstanding optical discovery which the world owes to Thomas Young. His evidence for the wave theory was strengthened when a prediction that he made in the case of Newton's rings received experimental confirmation." In January, 1809, Malus made the discovery that a ray of light reflected from polished glass at a certain angle will traverse Iceland spar as an ordinary or an extraordinary ray, according to the relative positions of the plane of reflection and the principal plane of the crystal. To those who held light to be a stream of corpuscles as well as to those who believed it to consist of longitudinal waves this phenomenon, called "polarization" by Malus, was a puzzle without a solution. Even Young and his followers could not explain it. To account for polarization Biot devised a complicated model of a molecule and published it in a treatise on physics in 1817. Professor Crew remarks: "His treatise of 1817 may, I think, be considered the peak accomplishment of the corpuscular theory. The darkest period in the entire history of wave theory is probably that bounded by the years 1909 and 1816; for in this latter year, came the fruitful discovery that two rays of light polarized in planes at right angles to each other cannot interfere—a discovery which led Fresnel to the hypothesis of transverse waves. During these seven years the only waves known 'in the best circles' were longitudinal ones." Fresnel, restrained by the contention of the great astronomer Arago, that transverse vibrations could not occur in the ether, delayed until 1821 the publication of his hypothesis of transverse waves. He then stated that it was in a conversation with Ampere that the suggestion of transversality arose. By 1829, through the union of Young's principle of interference with Huyghens' principle and with the hypothesis of the transversality of light waves there had been

evolved a conception of the nature of light adequate to explain nearly all the phenomena of light already known or to be come upon in the next half-century. Before his death at an early age in 1827 Fresnel had placed physics under an additional debt to him by furnishing a picture of the wave surface in biaxial crystals.

At the time of his death Thomas Young was working on a dictionary of hieroglyphics. "I once heard Ames remark that 'Thomas Young was the last of the men who knew everything.' In any event, whether we consider the native ability of this great Englishman, or his versatility or his energy or his straightforwardness, his example is an inspiration to every student of physics; and this Society does well to cherish his memory."

G. F. S.

Experimenting in Strong Magnetic Fields. P. KAPITZA. (*Proc. Phys. Soc.*, London, Aug. 1930.) Here is described with photographs the most powerful electromagnet in existence, to which Baron Rutherford devoted a considerable part of his address to the Royal Society last December.

To avoid overheating the electric current flows only .01 sec. and the changes in physical properties are recorded by oscillographs. As source of the current a single-phase turbo-alternator was used. Such machines give large currents when short circuited. Commercial machines of this type are built in such a way as to avoid the occurrence of large currents on short circuit, but for the purpose of this experiment a machine was made so as to deliver huge currents on short circuit. On the test bench it gave 220,000 kw. The advantage of employing an alternating current lies in this, that the interruption of the current is simplified by breaking it when the value is about zero. The current curve has a flat top, thus remaining constant in value for a few thousandths of a sec. "The most difficult part of the apparatus to design was the coil itself, in which the magnetic field was produced. The density of the current in this coil reached a value of 500,000 amp./cm.^{2}, and the electrodynamical forces which try to enlarge the diameter of the coil are so large that at first most of our coils broke with a great explosion. It was necessary to work out a method to reinforce these coils with steel bands and to find a coil of such a shape that the electrodynamical forces together with the reaction forces of the reinforcement should be reduced to a uniform (hydrostatic) force on the copper. The force on the outside reinforcement of the coil which is actually now in use, and in which fields of over 300,000 gauss have been obtained, reached the value of 140 tons."

For the magnetic phenomena taking place inside of an atom .01 is a very long time. Hence this brief interval is adequate for studies of the Zeeman effect, of the change of resistance in magnetic fields, of magnetic susceptibility and of change of dimensions (magnetostriction), when substances are placed in the strong though momentary field.

The intensity of the brief field may be roughly judged by this. If a Dewar flask containing an upright glass rod 3 mm. in diameter surrounded by liquid air have the intense field applied to it, the rod is thrown up to a height of 7 or 8 meters, because the liquid oxygen, being strongly paramagnetic, is drawn down into the flask, thus ejecting the rod. "If the Dewar flask is filled with liquid oxygen only, the force of attraction due to a field of 300,000 gauss produces a pressure of several atmospheres and the Dewar flask breaks."

Usually the change of resistance caused by applying a magnetic field to a metal is a small fraction of one per cent., but with Kapitza's electromagnet 20 to 30 per cent. is not uncommon and in some cases the resistance of bismuth increases 2,000 times.

G. F. S.

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